ELEMENTS OF

AVIATION ENGINES

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INTRODUCTION

HAVING *been forcibly impressed with the fact that many of those who take up the study of aviation are not familiar with gasoline engines and have little mechanical inclination, it has been the endeavor of the writer to explain in a simple way some of the points that appear to cause beginners the greatest amount of trouble. While it may aid those who are conscientiously reviewing the subject, it is far from the purpose of this book to provide a short cut to passing marks on examination papers.*

All of the information herein contained has been before the engineering public at one time or another. Realizing that certain new developments must not appear in print during this critical period every precaution has been taken to observe strict avoidance of revealing confidential information.

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CHAPTER I

THE AVIATION ENGINE

IN TAKING up a new subject it is often best to fix clearly in mind just what is meant by the name of the subject, so in beginning a discussion upon aviation engines it seems well to start with a rough definition of the term aviation engine. A simple statement that an internal combustion engine so designed that it is capable of lifting from the ground and sustaining in flight a heavier than air flying machine will suffice as a definition for our subject. By the term internal combustion engine is commonly meant simply a gasoline engine, because in such an engine the power is derived from the force of an explosion within a cylinder. This will make clear what we mean by our subject.

The question at once arises: Why must aviation engines be internal combustion engines instead of steam engines, and why not propel aeroplanes by aid of electricity? The answer is simply that maximum power and minimum

weight can be best obtained with the internal combustion engine. In the study of aeronautics weight is a tremendous factor, and it is interesting to note that not until the gasoline engine had reached its modern development was human flight practical. On account of the unlimited use of gasoline as a motive power and the increasing interest of technical men in the problems of aviation, the gasoline engine has been developed to such a point that it may deliver 1 H.P. for every 1.8 pounds of its weight. To a mechanical mind this seems one of the greatest achievements of the twentieth century.

Since gasoline engines have been used so extensively and with such marked success in automobiles, the aviation student will at once involuntarily compare the aviation engine with that in an automobile, and oftentimes he compares them wrongly by stating that the aviation engine develops a vastly greater speed than the engine of an automobile is capable of attaining. This is incorrect and is a poor way of comparing the two. The main difference is that of lightness. Aviation engines are of the lightest possible construction and are designed to run continuously at their highest speed.

Seldom are the frail supporting members for the engines in a horizontal plane, and often the engine is called upon to do its work while completely inverted. These are conditions that the automobile engine does not have to meet. In order to attain a construction that will fulfill the requirements imposed upon aviation engines, it is natural to expect that some sacrifice must be made. This accounts for their low degree of durability. When we examine the heavy construction of a 400 H.P. marine gasoline engine and then regard the frail parts of a 400 H.P. aviation engine there is not the slightest doubt which engine will continue longer in its operations. However, since light construction is an absolute necessity, it is useless to expect much in the way of durability, and as a means of knowing what an aviation engine will stand it is interesting to note that after every seventy-five hours of operation the engine should be rebuilt.

As a compact and light power plant the aviation engine is the highest attainment of mechanical genius. It has been developed from the type that propels the automobiles, and just as the old types of automobile engines do not resemble in appearance the types used to-

day, so the first aviation engines have little resemblance to those of the present time. The development has been rapid, and it is difficult to predict what will be the effect upon aviation if the rapid strides taken during the past ten years continue to add to the efficiency and reliability of the aviation engine during the next ten years to come.

CHAPTER II
APPLICATION OF THE BASIC PRINCIPLE

THE WORKING principle of an aviation engine is identically the same as that of the ordinary gasoline engine. In the middle of the nineteenth century it was satisfactorily proven that the explosive force of gasoline could be used to actuate a piston, and this has given rise to the adoption of a new form of motive power. Since that time gasoline engines have been developed along two lines, one being called the two-stroke cycle engine, and the other the four-stroke cycle engine, but since the former has not been used extensively in aviation work little attention will be given to it here.

A two-stroke cycle engine is one in which an explosion takes place in the cylinder every time the crank shaft makes one revolution. A charge of combustible gas is slightly compressed within the crank case by the piston traveling downward. Near the bottom of this downward stroke the piston uncovers a port in the cylinder wall allowing some of the compressed gas to enter the cylinder. Then the

piston moves upward, closing the port and compressing the gas. The charge is ignited when the piston is near the end of its upward stroke, and the result is that the force of the explosion violently drives the piston downward. An exhaust port on the opposite side of the cylinder from the intake port is uncovered as the piston sweeps downward, and the force of the explosion starts the burnt gas rushing out of the cylinder. The intake port having also been uncovered by this time will allow a fresh charge to enter. By using a deflector on the piston head the fresh charge is hindered from rushing straight to the exhaust port and is diverted upward, serving admirably to expel the remaining burnt gases. Now the piston is ready to go upward again, and the same operations are repeated. In this way the piston makes two strokes to complete a cycle, hence it is spoken of as the two-stroke cycle engine.

Some confusion may be caused by not knowing the exact meaning of the word cycle, so it may be well to insert here a definition. A complete series of events occurring in regular sequence and ending so that the same operation can be repeated in the same order is called a cycle.

The four-stroke cycle engine has proven the more satisfactory of the two types, and since it is the one used in connection with aviation, it is very desirable to fully understand it. This type differs from the two-stroke cycle in that it has two distinct mechanically-operated valves in the cylinder which, of course, necessitate a few more working parts. Instead of the gas being stored and compressed within the crank case, this engine draws its explosive charge directly from the carburetor by opening the inlet valve as the piston goes downward and making use of the suction thus exerted. The charge is compressed by the reversal of the piston's motion and the closing of the inlet valve. Near the end of this compression stroke the charge is ignited, resulting in an explosive force being exerted on the piston when it is ready to go downward again. Near the end of this succeeding downward stroke the exhaust valve is opened permitting the force of the explosion to give the burnt gases their initial outward impulse. The valve remains open during the entire upward stroke of the piston to insure all of the burnt gases being expelled. The clearing out of the cylinder is often referred to as scavaging the cylinder. Generally

the exhaust valve closes after the piston has reached its uppermost position. This brings us to the opening of the inlet valve and with that the sequence of events is repeated.

By the stroke of the piston is meant the movement of the piston in one direction. It follows from this that the length of the stroke is the linear distance the piston travels from its uppermost position to its lowest position or vice versa. The term stroke has come to mean simply the number of inches between top center and bottom center, thus designating the two extreme positions of the piston. To make clear the four strokes of the piston in a four-stroke cycle engine, the first one in which the piston goes down and draws in a charge is called the intake stroke. The next upward motion is the compression stroke. Then comes the explosion which drives the piston downward. This is the power stroke. Finally the expulsion of the burnt gases is the exhaust stroke, and this completes the cycle.

In aviation engines it is customary to ignite the charge near the end of the compression stroke instead of at the beginning of the power stroke. The speed of the engine justifies this. If ignition were to take place when the piston

was at top center or a little afterward, the force of the explosion would be exerted upon the piston head at such a late time that the piston could not deliver its maximum impulse to the crank shaft. When the piston is nearing bottom center its effectiveness for transmitting force is negligible. Consequently by opening the exhaust valve at the end of the power stroke instead of at the beginning of the exhaust stroke, the force of the explosion serves to start the burnt gases rushing outward without losing power. The exhaust valve is generally held open until the beginning of the intake stroke. This aids in scavaging the cylinder as it permits more time for the operation, and the danger of retaining some of the burnt gases is avoided since the out-going exhaust will possess a certain amount of inertia. Different makes of engines have different times for opening the intake valve. On some there is a small interval between the closing of the exhaust valve and the opening of the inlet valve, as is the case with the Curtiss OX and the Hall-Scott. This permits the downward motion of the piston to establish somewhat of a rarefication within the cylinder, so that when the inlet valve is opened there will be a ten-

dency for the gas to enter more promptly. The closing of the inlet valve occurs at the beginning of the compression stroke. The gas passing through the manifold will have some inertia which will maintain a flow into the cylinder during the first part of ensuing upward stroke. By thus keeping the valve open past bottom center a larger amount of gas is placed in the cylinder.

The question often arises: Why are not two-stroke cycle engines used for aviation work, on account of the decrease in weight due to the less number of working parts, the more frequent power impulses, and the need of an engine that will do its best work when running at top speed? The two-stroke cycle engine fulfills all the requirements demanded of an aviation engine except for the fact it will not ordinarily run satisfactorily at low enough speeds to allow the propeller to idle. Since a successful aviation engine must be able to run slow enough without stopping to allow the plane to glide, it can be easily seen that the present form of two-stroke cycle engine is poorly suited for aviation work.

So far in explaining the different operations involved in a cycle, only one cylinder has been

considered. It is advisable to have frequent power impulses and to avoid vibration as much as possible. This is accomplished by using a number of cylinders which decreases the weight of the reciprocating parts.

Vibration is due to the shifting of the centers of gravity of pistons and connecting rods. In a single cylinder engine of required power turning at a speed suitable to drive a propeller, the amount of vibration would be prohibitive. The greatest bearing pressure in an engine at high speeds comes not so much from the explosion, but from the effort of starting and stopping the weight of the piston and connecting rod. To decrease this reciprocating weight it is necessary to resort to the basic law of volumes and areas. If we make a body half the dimensions of another, it will have but one quarter of the area and only one-eighth of the weight. This can be applied to pistons. Thus a piston can be replaced by four smaller ones half as large, and the area of the four will equal that of the larger one. However, these four pistons will weigh practically one-half as much as the original single piston. This illustrates the way reciprocating weight is lessened and shows plainly the demand for a larger number of cylinders.

The way the cylinders are arranged serves as a means of classifying aviation engines. If the cylinders stay in a fixed position in respect to the crank shaft, it is spoken of as a fixed cylinder engine, but if the cylinders revolve about the crank shaft it is called a rotary engine. Various difficulties in construction are encountered when the number of cylinders is increased, so fixed-cylinder engines are not confined to the vertical style but are often built in a V form to permit a shorter crank shaft. A peculiar style of fixed-cylinder engine is that with an additional row of cylinders between the two rows that go to make up the V. This is the design of the Sunbeam Engine. Another style of fixed-cylinder engine is one in which the cylinders radiate from the crank case allowing the force of all explosions to be exerted upon the same crank pin. The Anzani engine is of this design. The rotary engines have not so many variations. As a means of increasing the number of cylinders a second bank of cylinders is often added, which of course necessitates two throws on the crank shaft. Rotary engines are limited to those having one and two banks. In both the fixed-cylinder and the rotary types the growing demand for an increased number

of cylinders has resulted in the adoption of engines of the designs just referred to for aviation work.

CHAPTER III
ENGINE SPECIFICATIONS

As a basis of comparing aviation engines certain specifications are used. It must be remembered that all engines are not called upon to do the same work, and furthermore that they are not all designed by one man or even by a group of men holding the same views on various mechanical problems. This will account for the wide range in specifications. In order to become familiar with the points where engines differ, a few items will be taken up here.

The first point to consider is whether the engine has fixed cylinders or is a rotary. If it is a fixed-cylinder engine, the arrangement of the cylinders should be noted. Generally speaking, rotary engines are used for very fast but brief flights, while fixed-cylinder engines serve better for long flights where speed is not so important.

The horse-power of an engine is probably the matter of greatest interest. All planes are not of the same size and weight, so there is need for engines of different power. One horse-power is the power required to lift 33,000

pounds a distance of one foot in one minute. The horse-power necessary to operate a plane is calculated by multiplying the total air resistance of the plane, expressed in pounds, by the speed in feet per second, then by 60 seconds in a minute, and dividing the product by 33,000. The actual horse-power that an engine develops is spoken of as brake horse-power. It may be found by measuring the torque exerted by the engine running with a propeller attached. By torque is meant the moment of tangential effort, or to put it more roughly, a force tending to produce rotation. The torque is allowed to be exerted upon an arm which delivers the force to a platform balance. By multiplying the force in pounds by the distance in feet through which it acts in one revolution by the R.P.M. and dividing the product by 33,000, the actual horse-power is obtained. The distance through which the force acts is the circumference of a circle having the power arm as a radius. This distance will be 6.2832 times the arm's length, so if we make the arm exactly 5¼ feet long, the distance through which the force acts will be 33 feet. This permits us to reduce our fraction to the lowest terms, making the denominator 1,000 instead

of 33,000. The horse-power can then be obtained by multiplying the torque expressed in pounds by the R.P.M. and then dividing by 1,000, which simply amounts to moving the decimal point three places to the left.

The weight of an engine is of great importance, for it determines the engine's fitness. As has been said before, aviation work requires maximum power for minimum weight. Lightness is the keynote of the whole engine, so the aviation engine is devoid of all unnecessary equipment. Self-starters are seldom used on account of their weight and mufflers never, on account of their weight and resistance also. Aviation engines avoid the use of a fly-wheel, on account of the large number of cylinders and also on account of the steadying effect of the propeller. In speaking of the weight of an engine, the weights of tanks and radiators are not included, nor does oil or water enter into the engine's weight. By dividing the weight by the horse-power the weight per horse-power is obtained. This is a very significant figure and is widely used in comparing engines. The most modern types of aviation engines range from two to three pounds in weight for every horse-power developed.

The speed of most aviation engines is generally about 1,400 R.P.M. being a compromise between the most efficient propeller speed and the most efficient engine speed. An ordinary propeller will do its best work when turning from 900 to 1,000 R.P.M. If it is driven considerably faster than that, it will cause what is known as cavitation, which means that the blades are working in an unfavorable medium so far as their usefulness is concerned. This will show the undesirability of having propellers turn at speeds which a high-grade automobile motor can easily attain. Consequently since the speed of an engine is normally greater than 900 or 1,000 R.P.M. it is advisable to compromise by driving the propeller a little faster than it ought to turn and running the engine at a reduced speed. The efficiency of an engine, which roughly speaking is the proportion between the energy received as work and the energy supplied as fuel, can be increased if the engine is permitted to run faster than 1,400 R.P.M. Since the propeller speed has limitations, engines running at higher speeds must have a gear reduction regarding the propeller. This is ordinarily accomplished by driving a jack shaft carrying

the propeller by spur gears one above the other. Sometimes internal gears are used and then the propeller will turn in the same direction that the engine turns.

The disadvantages of a geared propeller are that more weight is added and a slight amount of power is consumed by the gears.

The direction of rotation of an engine should be considered. When standing directly in front of the propeller and noting that it turns counter-clockwise, the engine is spoken of as having a normal rotation. Should the propeller turn clockwise the engine has an anti-normal rotation. One reason for building both normal and anti-normal engines is that in case a plane has two engines as is sometimes the case with bombing planes, then normal and anti-normal engines are used to equalize the torque effect.

The number of cylinders and their bore, meaning the internal diameter, is an important item. The stroke of the piston which has been mentioned before is often spoken of in connection with the bore. Various engines use different strokes with different bores, but for the sake of illustration, the stroke averages about one and one-quarter times the bore. If both the bore and the stroke are large, there will be

a tendency to develop heat on the compression stroke providing the compression chamber is small. The total piston displacement is calculated by squaring half the bore, multiplying by 3.1416, then multiplying by the stroke, and finally by the number of cylinders. The result will be in cubic inches. The horse-power per cubic inch of piston displacement, which is obtained by dividing the horse-power by the displacement, is a figure of much interest. Efficient motors will give from .17 to .27 H.P. for each cubic inch of displacement.

Ignition, carburetion, and cooling enter into the specifications of an engine, but since separate chapters are devoted to them later, they need not be dealt with here.

CHAPTER IV
ENGINE PARTS

To take up all the parts of an engine and describe them fully would be a big undertaking, and might not prove interesting to those beginning this subject. Consequently only the principal parts will be included and dealt with in a very brief manner.

The cylinders of a gasoline engine are variously constructed. They may be made as individual units, or several may be cast in block. The advantage of the former method of construction is that more complete jacketing can be accomplished, while rigidity is the advantage of the latter type. In case an engine had four cylinders cast in block and one became damaged, then the three good ones would have to be discarded in order to replace the one cylinder that caused the trouble. This waste is not encountered when each cylinder is a separate replaceable unit. However, from the standpoint of compactness the block construction is by far the more preferable. Individual cylinders are made of cast iron, semi-steel, and steel. When cast in block their material is

usually aluminum alloy. A peculiar form of construction is that used in the Curtiss cylinders, where each cylinder is of cast iron with a band of some non-corrosive metal such as monel metal to act as a water jacket. The cylinders of the Hispano-Suiza are unusual in design, being steel thimbles that screw into an aluminum alloy water jacket designed to hold four cylinders. The Sturtevant cylinders are interesting in that they are of aluminum alloy cast in pairs with a steel liner shrunk in to act as a cylinder wall.

The location of the valves determines the shape of the cylinder head. If the valves operate in extensions on opposite sides of the combustion chamber the cylinder is said to have a T head, since its shape is that of a T. This construction necessitates two independent cam shafts besides being rather bulky, so is of little importance from the standpoint of aviation work. If a cylinder has only one extension in which a valve or valves work, its shape will resemble that of a Greek letter gamma or simply an inverted L. It is therefore called an L head. When a cylinder has no extensions on either side but has two valves located in its head, it is called an I head cylinder. This type

of cylinder is the most popular for aviation engines, because it does away with an irregularly-shaped combustion chamber. In the case of a T or L head cylinder the space above the valves may be regarded as a pocket, and very often it is difficult to scavage these pockets. The placing of both valves in the head permits the combustion chamber to be made slightly spherical in order to reduce the surface area and lessen the amount of heat carried away at the time when an explosion takes place.

Some cylinders are made so that the head may be removed without disturbing its base. This is known as a detachable head and has the advantage of providing an easy means of removing carbon and working upon the valves. However, a little more material is required in this construction, and it brings into account compression leaks and also water leaks since the cylinder heads must be jacketed.

The crank case is generally divided into two parts; the top section serving as a base for the cylinders and the bottom section carrying a supply of oil. The sump is that part which holds the oil. As a rule crank cases are aluminum castings, and in case the motor is a V type great care is taken to strengthen the upper sec-

tion by means of partitions or webs to prevent the strain exerted by explosions on opposite banks from cracking the upper section. The crank shaft bearings are generally held in the upper section. Sometimes the lower halves of the bearings are held in partitions in the lower section of the crank case, as in the Hispano-Suiza. The difficulty in this construction is that the lower section can not be removed without disturbing the crank shaft. As a means of retaining the oil in the sump when the engine is momentarily inverted, splash pans are placed in the lower section. They do not retain all of the oil, but aid in reducing the amount that would otherwise rush into the cavities of the pistons. The vents on crank cases are called breathers. These maintain atmospheric pressure in the crank case even though compression leaks are present.

That part of the engine which is driven downward within the cylinder by the force of an explosion is the piston. Pistons have received as much if not more attention by designers than any other part of the engine, and the result has been to secure satisfactory operation at high speeds and at high temperatures. The material used in piston construction is

generally aluminum alloy, although cast iron is sometimes used. The use of aluminum as piston material serves to lessen vibration and increase the speed, lessening the weight of reciprocating parts. Another reason for its use is the rapidity with which it conducts heat. The piston head may be either convex, flat, or concave, and all of these shapes are in use at present. The convex or domehead brings into account the ability of an arch to withstand strain. Greater strength for a given amount of material is obtained by using a convex head. The flat head is the common type. By having a flat surface less area of the piston is exposed to absorb heat. This results in a slightly cooler piston, which is a big advantage, as it is impossible to cool the piston in the same way that the cylinder is cooled. The concave head has been extensively used on rotary engines because it permits a shorter cylinder and thus lessens the centrifugal force. This shape of piston head allows the combustion chamber to assume a spherical form. By the bosses are meant the two projections within the piston that hold the wrist pin, and it follows that the upper end of the connecting rod must fit between the two bosses. The lower portion of a piston is termed the skirt.

Due to more material at the head and also on account of the top surface coming in direct contact with the heat of each explosion, it will be seen that the upper part of the piston will expand more than the skirt. This necessitates allowing more clearance between the cylinder wall and the piston at its head than at its skirt. Some idea of this difference can be had by pointing out that a five-inch piston may be cleared .020 inch at the skirt and as much as .027 at the head.

To prevent compression and the force of an explosion from passing down between the piston and the cylinder wall, piston rings are used. These fit in grooves in the piston and bear upon the cylinder wall. Besides preventing leaks these rings prevent much oil from getting upon the piston head where it would result in the formation of carbon. The rings are made of cast iron, and each piston generally requires two or three of them. When the two ends of a ring come together squarely the ring is said to have a butt joint. When the ends meet each other diagonally it is called a diagonal joint. Likewise if the ends are made so that they meet each other in the form of a step, it is called a step or lap joint. Obviously

a ring having a step joint will offer more resistance to the passage of gas than those having butt or diagonal joints. A precaution to take in placing a piston in a cylinder is to make sure the joints in the rings are at equal intervals around the circumference of the piston.

The wrist pin is made of steel, usually hollow and case hardened, and is used to form a movable joint between the piston and the connecting rod. Its length depends upon the diameter of the piston. There are three general ways of retaining the pin in its right position. It may be held rigidly in the connecting rod by means of a clamp or a set screw which results in the pin turning in the piston bosses as the connecting rod moves back and forth. This method is used in the Curtiss OX. Another way is to pin the wrist pin in the bosses so that it is securely held in a fixed position. The connecting rod will then turn on the wrist pin which means the bearing will be in the connecting rod. Such a construction necessitates a bearing at both ends of the connecting rod. The Hall-Scott A5A has its wrist pins held rigidly in the piston bosses. The floating method such as used in the Sturtevant allows the pin to move either in the bosses or in the

connecting rod. Brass ends on the pin or caps over the ends of the bosses protect the cylinder walls.

The connecting rod is a steel arm used to convert the reciprocating motion of the piston into the revolving motion of the crank shaft. The majority of connecting rods have a cross section resembling an I, although H and tubular rods are not uncommon. In cases where the wrist pin is held in the bosses the upper end of the connecting rod is supplied with a bronze bushing that acts as a bearing surface. The lower bearing, in which works the crank pin, is given more attention. Babbitt is employed as a bearing metal and is generally backed by bronze to take its place should enough heat be developed to fuse the babbitt. Lower connecting rod bearings are made in two pieces to permit the crank pin being put in position. Between the two halves of the bearing are placed strips of metal called shims. These are .001, .002 and .005 inch thick and as the bearing wears away these can be removed insuring a better fit. In a V motor, when the vertical axis of opposite cylinders are in the same vertical plane, the connecting rods of opposite cylinders will meet the crank pin at the same point.

This will necessitate the forked or straddled construction in which one rod works between the fork of another. It makes rather a complicated and costly bearing, but it is a favorite design and is being used extensively. The Hispano-Suiza has this type of lower connecting rod bearings. Another and simpler way is to have the cylinders "staggered" by placing the cylinders on one bank a little ahead or behind those on the opposite bank, thereby allowing two lower connecting rod bearings to work side by side on one crank pin. A wise precaution to take in assembling a motor is to make sure the lower connecting rod bearing is such that it allows the wrist pin to be absolutely parallel with the crank pin. If it is otherwise the piston will not work freely within the cylinder.

The crank shaft is the driving shaft of the engine to which the power impulses are transmitted by the pistons and connecting rods. It is needless to say that this is the most important moving part of an engine, and for this reason it is made with great precision from selected pieces of high-grade steel by drop forging and subsequent turning. The principal parts of a crank shaft are the main bearings,

the cheeks, and the pins on which the connecting rods work. Two cheeks and a pin are spoken of as a throw. Thus the number of cylinders govern the number of throws, and also upon the number of cylinders depends the number of degrees between the throws. In a vertical motor, if the cylinders are cast separately, there is generally a main bearing between every two throws. Where the cylinders are cast in block there is not so much space between the pistons which often means a decrease in the number of main bearings. The crank shaft used in a V motor is identically the same as one used in a vertical motor having half the number of cylinders. Two connecting rods are fitted to each throw, and if the cylinders are cast separately a main bearing is placed between every two throws.

For the main bearings of a crank shaft the lining is babbitt usually backed by bronze very similar to the lower connecting rod bearings. Babbitt, which essentially consists of lead and antimony, is used as bearing metal because of its anti-friction properties, its sufficient hardness, and the ease with which it can be replaced. Lead alone possesses considerable anti-friction properties, but is impracticable on account

of its softness. The addition of some antimony will materially harden the lead without lessening its anti-friction properties. The use of babbitt also permits the liner to be scraped to secure an exact bearing surface. By coating the journal with Prussian blue, the high spots can be detected on the liner, and these can be successively removed by scraping.

To have evenly placed power impulses the throws on a crank shaft must be placed at certain angles with one another. In any four-stroke cycle motor all cylinders will fire once in two revolutions of the crank shaft or once in 720 degrees. In a four-cylinder motor there would be four explosions in 720 degrees, and to get equal spacing the power impulses would have to come one-fourth of 720 or 180 degrees apart. This will explain why the angle between two throws that receive impulses, one directly after the other, is 180 degrees for a four-cylinder crank shaft. The throws in a six-cylinder crank shaft are 120 degrees apart, since there will be six power impulses in 720 degrees.

In determining the order in which the cylinders will deliver their power impulses to the crank shaft, it is the custom to fire them so

that the vibrations set up by one explosion will serve to counteract the vibrations caused by a previous explosion. To accomplish this an explosion at one end of the shaft is followed by an explosion near the other end.

Here we come to what is known as the firing order, which simply means the order in which the cylinders do their work. In order to discuss the firing order it is first necessary to explain how the cylinders are numbered. In American practice cylinder No. 1 is always that one at the pilot's end of the engine, and the numbering is in regular order toward the propeller. In V engines No. 1 is the first cylinder on the left bank viewed from the pilot's cock pit. Some engines have the left bank numbered L1, L2, L3, L4, and the right bank R1, R2, R3, R4. Others number the left bank 1, 2, 3, 4 in the regular way and then start with the cylinder nearest the propeller on the right bank calling it 1′ followed by 2′, 3′ and 4′ going toward the pilot's end. The Curtiss OX has the peculiar way of starting with No. 1 on the left bank nearest the cock pit and designating as No. 2 the opposite cylinder on the right bank. No. 3 is the next one on the left bank, and in this way the odd numbers are on

the left bank and the even numbers on the right bank.

To return to firing orders, it is best to start with a four-cylinder engine. The cylinders in such an engine can be fired in a 1, 2, 4, 3 order or in a 1, 3, 4, 2 order. From this it can be seen that throws 1 and 2 are 180 degrees apart and 3 and 4 are also that distance apart. Likewise it is evident that with a four-cylinder crank shaft, pistons 1 and 4 travel together and also 2 and 3 are coming up or going down together. The two usual ways for a six-cylinder engine to fire are 1, 5, 3, 6, 2, 4, and 1, 4, 2, 6, 3, 5. Here the throws are 120 degrees apart, and the pistons that travel together are 1 and 6, 2 and 5, and 3 and 4. V engines use the basic four-cylinder and six-cylinder firing orders to fire the two banks. The explosions will alternate between the two banks starting with the cylinder at the pilot's end on the left block and followed by the forward cylinder on the right block. Explosions will occur on the left bank according to either one of the two firing orders, and those on the right bank in like manner except that on the right bank we will be working from the propeller end toward the pilot's end. Where an engine is numbered L1, L2,

etc., and R1, R2, etc., its firing order may be:

L1, R6, L5, R2, L3, R4, L6, R1, L2, R5, L4, R3.

Where the left bank is numbered 1, 2, 3, etc., and the right bank 1′, 2′, etc., in the opposite direction, the firing order may be:

1,1′, 5,5′, 3,3′, 6,6′, 2,2′, 4,4′.

The Curtiss OX with its peculiar cylinder numbering already referred to has the following distinctive firing order for normal rotation:

1, 2, 3, 4, 7, 8, 5, 6.

For an anti-normal engine it would be:

2, 1, 4, 3, 8, 7, 6, 5.

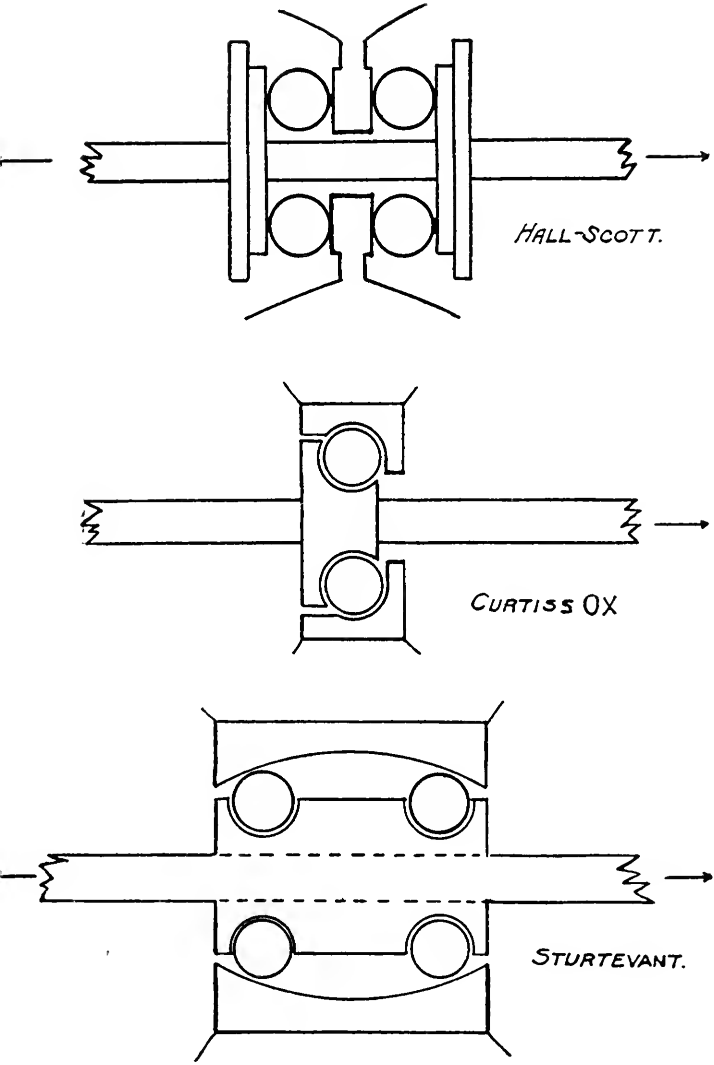
or to start the cycle with an explosion in cylinder No. 1 it would be:

1, 4, 3, 8, 7, 6, 5, 2.

In order that the thrust exerted by the propeller upon the crank shaft may be transmitted to the crank case and then to the fuselage, a thrust bearing is placed upon the crank shaft very near the propeller hub. Thrust bearings are generally ball bearings having either one or two rows of balls and very often they are designed to take a load directed at right angles towards the center of the shaft as well as taking care of the thrust. In an engine

like the Curtiss OX, where the crank shaft extends several inches between the last main crank-shaft bearing and the propeller hub, the thrust bearing will be the last point where the shaft may be supported. Now if a shaft is allowed to revolve without a radial bearing at its end vibration will result and this must be avoided. Consequently on the Curtiss OX and all other engines having a nose, the thrust bearing must be capable of taking both radial and thrust loads. Some thrust bearings having a single row of balls will only take thrust in one direction. This makes it necessary to reverse the bearings if an engine is transferred from a tractor plane to a pusher plane or vice versa.

The cam shaft is that part of the engine having irregularities upon its surface that open and close the valves at the proper time. The irregularities are called cams and are usually accurately shaped projections upon the shaft for imparting the necessary motion to a valve. Cam shafts are always made of high-grade steel and the cams are forged integral with the shaft. When gasoline engines were first being developed it was the practice to have as a cam shaft a plain piece of shafting with the cam keyed or pinned to it in the right position.



THRUST BEARINGS

This resulted in an endless amount of cam-shaft trouble as the cam would often come loose causing a valve to operate at the wrong time or possibly not operate at all. Now that the cams and shaft are made in one piece, this difficulty is no longer encountered.

The location of the cam shaft has been a matter of much discussion. The old practice was to have it located at the base of the cylinders as this was the most convenient position where T and L head cylinders were used. Since I head cylinders are more favorably looked upon, the overhead position of the cam shaft is being used more and more, as it does away with the numerous push rods used to operate the overhead valves. However, a cam shaft so placed necessitates a pillar shaft and bevel gears to drive it. V engines that use the base position of the cam shaft usually have the cylinders placed in a staggered position. This makes it much easier for one cam shaft located at the bottom of the V to operate the valves on both banks of cylinders. When a V engine uses the overhead position two cam shafts are necessary.

In all four-stroke cycle engines the cam shaft always travels at half the crank-shaft speed.

The reason is that it takes two revolutions of the crank shaft to complete a cycle and that the individual valves must open but once during a cycle. For instance, one cylinder will fire once during two revolutions of the crank shaft. In order that it may function, an inlet valve must open once to let a new charge in. Then the intake valve will open once during two revolutions of the crank shaft which means that the cam operating that valve must revolve once to two revolutions of the crank shaft.

Upon the valves depend to a great extent the success of the engine, for aviation engines seem particularly susceptible to valve trouble. The two general types of valves for gasoline motors are the poppet or mushroom type and the sliding sleeve type. The former is universally used for aviation work largely because the latter type brings into account a little more weight. A poppet valve consists primarily of a disk with a bevelled edge and a stem joining the disk at its center. The bevelled edge is usually at an angle of 45 degrees with the plane of the disk, although other angles are not uncommon. By having the valves open inwardly the force of an explosion or the force of a com-

pression stroke will tend to push the valve firmly against the bevelled portion of the cylinder referred to as the seat, and in this way the greater the force within the cylinder the more tightly will the valve be held in its closed position. It is safe to say that valves in aviation motors should be as large as possible. The use of I head cylinders restricts the size of the valves, so it is often impossible to put in a valve of a satisfactory diameter. T and L head cylinders permit the use of larger valves on account of the extension to the combustion chamber. The object of using large valves is simply to charge and scavage a cylinder more rapidly.

When we consider under what conditions the valves must do their work, it will be seen why a great deal of attention has been paid to the materials of which they are made. The exhaust valve opens on the power stroke allowing the highly-heated gases to escape around it. Particles of carbon will invariably be carried outward and some will at times be caught between the valve and its seat at the instant it closes. The valve having been highly heated on account of its direct contact with the explosion, will be somewhat soft, and when

it snaps against the particle of carbon a small indentation will be caused. This is called pitting, and to lessen it to a great extent it has now become the custom to make the exhaust valve of tungsten steel. Of the two valves the inlet is less subject to pitting, since the incoming gas tends to cool it, and furthermore less carbon collects on its seat. Nickel steel is the material sometimes used for inlet valves.

In order to make a valve seat more firm after an engine has run considerably, and to prevent leaking, it is necessary to grind a new surface both on the valve and its seat in the cylinder. The abrasive is called grinding compound. It is applied as a very thin paste to either the valve or its seat, whereupon the valve is inserted in its usual position and vigorously turned back and forth. If care is taken to frequently unseat the valve the compound will be kept evenly distributed over the grinding surface, and there will be little danger of cutting rings in either the valve or its seat. Prussian blue can be used to determine the fit. Frequently a valve may become warped or a shoulder may develop on the seat. A reamer can then be used to good advantage, but it must be followed by grinding. Sometimes the

guide in which the valve stem works will become worn, making it useless to grind a valve until a bushing or new guide has been supplied.

The springs used to close the valves deserve attention. On some engines double-coil springs are used, and then in case a spring breaks there will still be one to close the valve. Occasionally the exhaust valve springs will be a little heavier than those on the inlet valves. This is to allow for any decrease in strength caused by the heat from the exhaust valve and also to prevent any possibility of the exhaust valve being pulled down on the intake stroke.

The ways in which the force of a revolving cam is brought to bear upon a valve stem are numerous and interesting. With an L head cylinder where the cam shaft runs directly under the valve, it is a simple matter to have a follower riding the cam and a tappet rod between the follower and the valve stem. When the cam comes up the valve will be pushed up. As the cam goes on the spring will bring the valve back to its seat. This is simplicity itself, but the use of I head cylinders makes necessary other means of transmitting the cam thrust.

The usual way of operating valves in the

cylinder head by a cam shaft located at the base of the cylinders is to use push rods connected to rocker arms working on fulcrums attached to the tops of the cylinders. As the push rod is forced up, one end of the rocker arm goes up and the other end goes down, pushing inwardly on the end of the valve stem. This is the way the valves are operated on the Curtiss VX and the Sturtevant. The peculiarity in the Sturtevant is that the side thrust imparted to tappet is avoided by having a pivoted arm ride the cam and on this arm rests the tappet. Worn guides are reduced to a minimum in this way.

The inlet valve operation on the Curtiss OX is interesting inasmuch as it brings into account a new form of cam, and also because the valve is pulled open instead of receiving a direct thrust. Upon the cam shaft for each inlet valve are two cams that would be completely circular but for a flat space on each. The space between these two cams is taken up by the exhaust valve cam, which is the ordinary type of cam. Upon the two round cams rests a tappet to which is attached a rod, or strictly speaking a tube, having a coil spring held about it at the top by a strap and at the

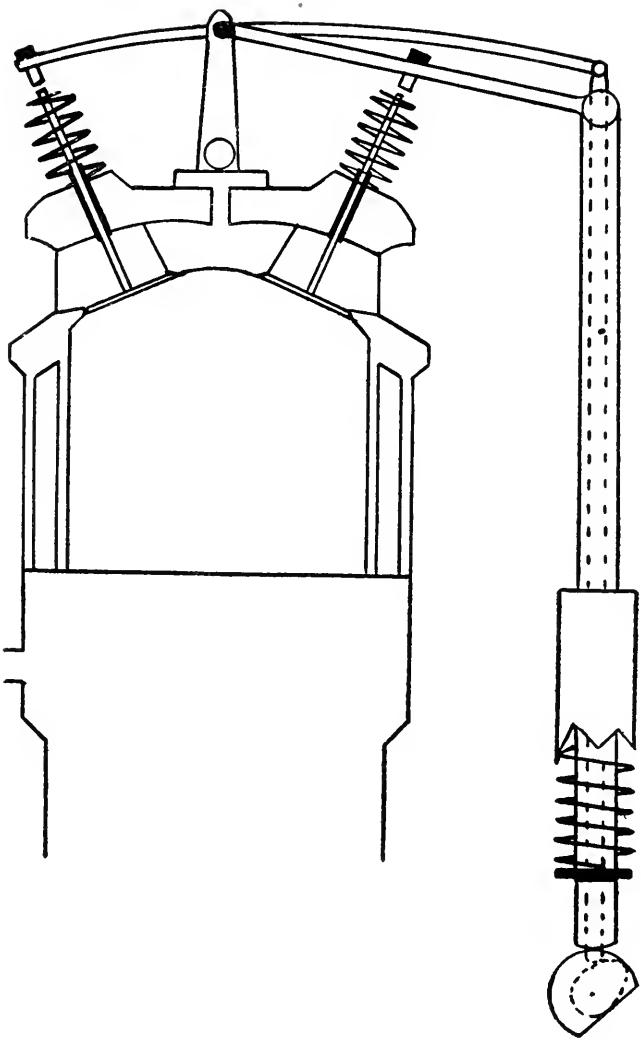


DIAGRAM TO ILLUSTRATE THE CURTISS OX VALVE ACTION

bottom by a collar upon the tube. The upper end of the tube is hinged to a lever arm that extends almost horizontally from a fulcrum upon the head of the cylinder, and directly under this lever arm is the end of the inlet valve stem. As the cam shaft revolves the flat spaces on the two cams will allow the spring to force the tappet and tube toward the center of the cam shaft, which results in a downward motion of one end of the lever arm. Since the inlet valve is located beneath it and since the spring on the tube is several times stronger than the spring upon the valve stem, the inlet valve is thus pulled open and remains open as long as the flat spaces will permit the spring to keep the tube in its downward position. It will be noticed that in this manner of opening the inlet valve everything depends upon the spring on the pull tube.

Making the valves open and close at the right time on an engine or timing the valves, as it is generally called, is a simple matter providing it is done systematically. The first thing to do is to select a cylinder, preferably No. 1 and, making sure a cam is not in a position to deliver a thrust, adjust the clearance of a valve on that cylinder by means of a feeler

gage so that the clearance is that given by the manufacturer. Valve clearance varies between .010 and .030 inch, and its purpose is to allow for expansion of the stem and also to obtain a very accurate adjustment of a particular valve. It is the custom to time on the opening of an intake valve or on the closing of an exhaust valve. After the clearance has been adjusted for one valve and after the cam shaft gears have been unmeshed, the engine is turned in the direction it is intended to rotate until the piston in the selected cylinder is exactly in the right position for the inlet valve to open or for the exhaust valve to close. Then the cam shaft is revolved by hand in the direction it is intended to turn until the inlet valve is just starting to open or the exhaust valve has just closed as the case may be. The next step is to mesh the cam shaft gears. Sometimes the teeth come directly together and when that is the case it is necessary to "split a tooth." Different engines have ways of doing this, but it generally amounts to providing some means of revolving the gear wheel upon the cam shaft the distance of half a tooth, which is enough to allow the teeth to be meshed without disturbing the cam shaft.

All of the other valves on the engine are timed by adjusting the clearance for each one. A piston is placed in the right position for a valve to open or close and if it does not function correctly the clearance is changed until it opens or closes on time. From this it can be seen that if the cam shaft is out of time all valves will be affected, while if the clearance is set wrong it will affect only the valve having the wrong clearance. In other words, the cam shaft affects every valve, while clearance affects the individual valve. In cases where too much clearance is given above a valve stem the valve will open late and close early. When there is too little clearance, the valve will open early and close late.

When spark plugs are placed in the cylinder head it is possible to determine the position of a piston at any time by removing a plug and inserting a steel scale. If valves are timed by determining a piston's position in this manner, it is spoken of as the linear method of timing. Inaccuracies may result from the use of this method where the pistons have convex heads and where particles of carbon are deposited on the piston heads. A more accurate method is to make use of a timing disk attached to the

crank shaft near the propeller hub. The circumference of this disk is divided into degrees with the points for opening and closing of each valve plainly marked upon it. If the disk is placed accurately upon the crank shaft it furnishes an excellent means of timing the valves, because no linear measurements need be taken. Since the angle of a crank throw must be used when working with a timing disk, this is called the angular method of timing valves.

CHAPTER V
CARBURETION

IN ORDER that gasoline may be mixed with the right amount of air to form an explosive mixture within the cylinders, it is necessary to make use of a device known as a carburetor. A great deal of attention has been devoted to the designing of carburetors, for it can be readily seen that the fuel consumption of an engine will be governed largely by the performance of the carburetor. Also of late much attention has been given to the carburetion of lower grade fuels, so the subject of carburetors is becoming a broad field.

A suitable mixture for an aviation engine is one pound of gasoline to fifteen pounds of air. A richer mixture would be one having more gasoline, while one having more air would be a leaner mixture. It has been found that the most practical way to obtain this mixture is to spray the gasoline into the air, and this is best accomplished by making use of a jet attached to a reservoir and lessening the atmospheric pressure about the jet. If the level of gasoline in the reservoir is slightly lower than the tip

of the jet and the jet is located in an air-supplied chamber having a connection with the inlet valves, the downward motion of the pistons will result in less pressure being exerted upon the gasoline in the jet than that in the reservoir, where atmospheric pressure is exerted. Gasoline in this way will be made to flow from the jet, and since considerable air is being drawn past the jet it will tend to form a spray of the gasoline that is being delivered.

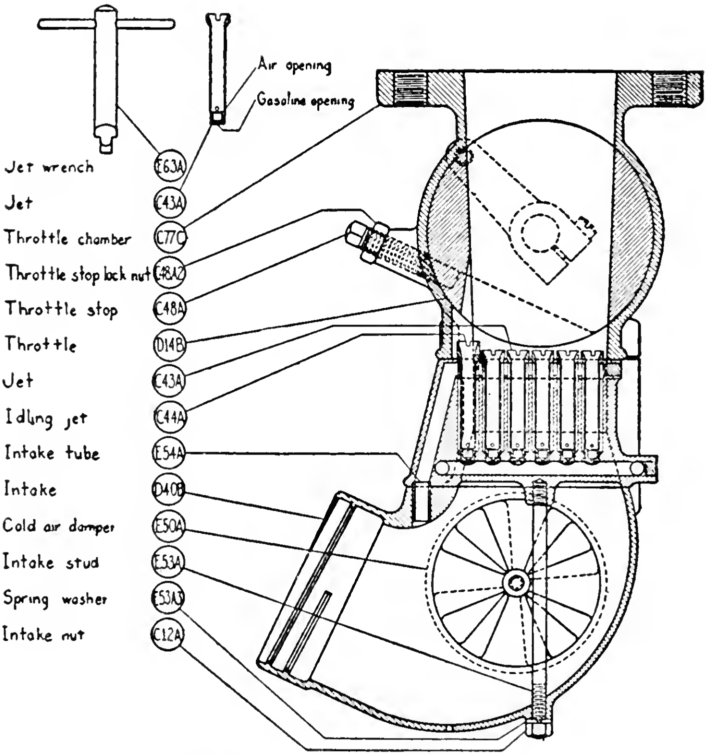
To restrict the amount of gasoline that is supplied to the float chamber which in turn has a great deal to do with the gasoline delivered by the jet, the float with which the float chamber is supplied, actuates a pin that opens and closes the main supply valve. Upon the top of the float rest the ends of two pivoted arms having the other ends in contact with the needle valve stem. As gasoline enters the float chamber the float will rise causing one end of the arms to rise and the other end to exert a downward pressure upon the needle valve. The result will be to seat needle valve allowing no more gasoline to enter until some has been drawn off by the delivery from the jet. From this it can readily be seen that the float cham-

ber is essentially a reservoir supplied with an automatic valve.

The space around the jet is called the mixing chamber. To admit the necessary air an opening is located somewhere below the level of the jet which insures all of the air passing the jet. As a means of diverting the air nearer the tip of the jet and thus securing more of a drawing effect, the space around the jet through which the air passes is lessened by the insertion of a choke tube or a venturi as it is often called. Its purpose is to increase the velocity of air as it passes by the jet and thus increase the suction at the tip of the jet. To regulate the speed of the engine a butterfly valve is located just a little distance above the choke tube. This valve, which is nothing more than a disk of metal, is often referred to as the throttle. When it is opened the speed of the engine is increased on account of a greater volume of gas being taken by the engine. As it is brought toward a closed position, less gas will be supplied, and the result is to decrease the speed of the engine. Stop screws are provided to prevent the throttle from closing completely, for that would cause the engine to cease running altogether.

So far the most elementary type of carburetor has been discussed. It is one that consists primarily of a float chamber and one jet in a regularly shaped mixing chamber. This is called a simple jet carburetor, and its chief weakness lies in the fact that at high speeds it will deliver a richer mixture than when the engine is running slowly; the reason for this being that as the speed is increased the suction is greatly increased, which means more gasoline in proportion to the air at high speeds than at low speeds. A simple jet carburetor adjusted for low speeds will use too much gasoline at high speeds, while one that is adjusted for high speeds will not supply enough gasoline at low speeds. Consequently simple jet carburetors are not satisfactory for aviation engines.

In order to secure the right mixture at both low and high speeds, several modifications of the simple jet carburetor have been used with more or less success. One way is to have the mixing chamber supplied with an auxiliary air valve that is held in place by a weak spring. At low speeds the spring holds the valve closed, but as the speed is increased the valve is drawn open due to the increase in suction.

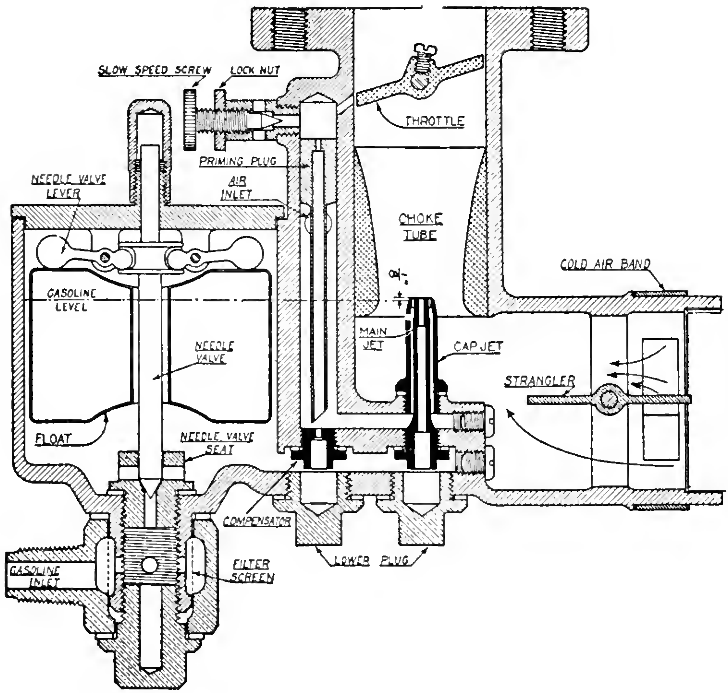


THE MILLER AVIATION CARBURETOR

This allows more air to enter the mixing chamber at high speeds causing the mixture to become slightly leaner and thereby securing approximately the same mixture at high speeds as at low speeds. Another way is to have the opening in the jet supplied with a metering pin which is nothing more than a slender pin tapered to a point that extends within the jet. As the throttle is opened, the metering pin is withdrawn much more slowly proportionately than the throttle is turned. This will allow a slightly greater amount of gasoline to issue from the jet at high speeds than at low speeds, but if arranged correctly the increase in gasoline will be in proportion to the increase in air. A third way is to employ several jets instead of one, and by using a rotary throttle uncover them one at a time as the speed is increased, allowing the air to pass by more than one. In this manner at high speeds more jets are exposed to the suction than at low speeds, and likewise the size of the air opening is larger at high speeds than at low speeds. A uniform mixture for all speeds is thus secured. A fourth way is to combine two small jets so that one will deliver more and more gasoline as the speed is increased and the other will deliver

only a limited amount. At high speeds the increased amount of gasoline from one will be just enough to take care of the additional amount needed. At low speeds both jets work harmoniously. Such departures from the simple jet carburetor are spoken of as speed compensations.

The Zenith carburetor has been widely used in connection with aviation engines, and for that reason it will be well to become familiar with its operation. The principle used is that of two small jets with one having only a limited amount of gasoline to supply. In appearance it closely resembles a simple jet carburetor except for a narrow cylindrically-shaped well between the float chamber and the mixing chamber. Gasoline is supplied from the float chamber to this well through a small hole in a plug that forms the bottom of the well. The plug is called the compensator. In the upper part of the well is a hole which allows atmospheric pressure to be exerted upon the gasoline within. One jet is placed within the other, and the inside jet is that one connected directly to the float chamber. Obviously this jet, which is known as the main jet, will act the same as one in a simple jet carburetor causing a richer mix-



A HALF SECTION VIEW OF A ZENITH CARBURETOR

ture at high speeds than at low speeds. The outside jet or cap jet, as it is called, receives its supply of gasoline from the well, and since the amount of gasoline furnished to the well is limited by the hole in the compensator, it can be seen that the amount of gasoline delivered by the cap jet is restricted to that amount that will flow by gravity through the hole in the compensator. At low speeds both jets work normally, but as the speed is increased the main jet will furnish more and more gasoline while there will be a tendency to draw more gasoline from the cap jet than can be supplied by the hole in the compensator. The result will be to exhaust the supply in the well and use instantly that which is fed to it. Since there is an air hole near the top of the well undue suction upon the compensator will be prevented. It should be noted that air will enter the well and be drawn out the cap jet at very high speeds, but it is absolutely wrong to regard the air hole in the upper part of well as an auxiliary air valve. The compensation effect comes from the fact that the increased amount of gasoline supplied by the main jet is enough to make up for that which is not supplied by the cap jet.

At idling speed very little air is drawn in, and this is not sufficient to fully overcome the surface tension of the gasoline in the jets. By surface tension is meant the force that tends to resist breaking the surface of the column of gasoline in the jet and drawing it outward. To insure a good mixture at idling speed the Zenith is equipped with an entirely separate carburetor that supplies its gas at a point where the air passes by the nearly closed throttle, and, on account of the small space, considerable suction is developed at this point. This carburetor gets its supply of gasoline through a tube leading down near the bottom of the well. The tube is held in what is called the priming plug, which acts as a cover for the well. The size of the hole in the priming plug governs the amount of gasoline fed to the idling carburetor. The amount of air that is allowed to enter the mixing chamber of the idling carburetor is controlled by a thumb screw known as the slow-speed screw.

To facilitate starting, a strangler valve is placed in the air inlet. If it is brought toward a closed position a greatly increased amount of gasoline will be drawn from the jets, and from this increased amount the more readily vola-

tile parts will go to furnish a combustible mixture. The strangler is used only in starting.

The variables are those parts affecting the mixture which can be replaced by similar ones having different dimensions. In naming them they are generally given in a regular order beginning with the choke tube, then the main jet, the compensator, and finally the priming plug. The cap jet is not a variable. Zenith settings comprise the internal diameter of the variables. The choke tube is measured in millimeters and the other three in hundredths of a millimeter. The size of a carburetor is the diameter in inches of its connection with the manifold.

The adjustments on the Zenith are the throttle stop screw, which governs the suction upon the idling carburetor, the slow-speed screw, to adjust the priming plug's delivery, and adjusting the level of gasoline in the float chamber by changing the position of the needle valve seat. This is accomplished by adding washers under the seat if the level is to be lowered or by withdrawing washers if the level is to be raised.

As a plane goes from a low altitude to a higher one the effect upon the carburetor will be to furnish a richer mixture, since the same

volume of air will be used, yet its weight will be appreciably decreased. One way of compensating for altitude is to have an air valve located in the manifold that can be opened by the pilot as necessity calls for. The effect of opening this valve will be to allow a little air to be added to the rich mixture. Another method is to decrease the pressure upon the level of gasoline in the float chamber by opening a valve in a tube leading from the float chamber cover to the manifold. The reduced pressure within the manifold in this way is used to slightly reduce the atmospheric pressure upon the gasoline in the float chamber. The effect will be to cause less difference in pressure between the gasoline in the float chamber and the gasoline in the jets, resulting in a decrease in the amount of gasoline delivered at the jets.

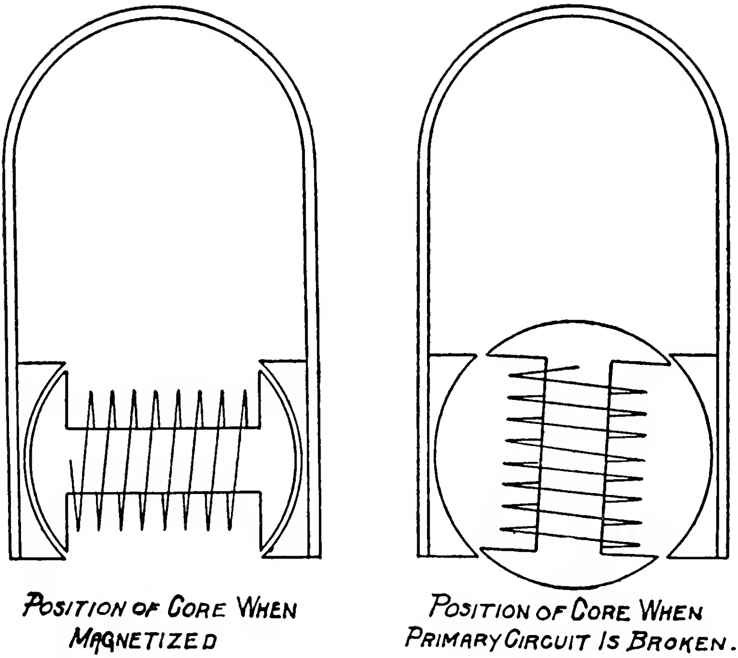
CHAPTER VI
IGNITION

THE ELECTRIC spark, which is the only satisfactory means of igniting a charge of gas in an internal combustion engine, is furnished by current coming from batteries or a magneto. In a battery electricity is generated by chemical action while the magneto is a mechanical means of generating electricity. Although the care of a battery is important, there is no call for an extensive knowledge of battery construction to keep it in good condition. With a magneto, however, there are many moving parts which need attention and frequently adjustments are necessary, so it seems advisable to take up the magneto rather fully.

To start with the fundamentals of electricity it will be remembered that if a coil of wire is revolved between the poles of a horseshoe magnet so that it cuts the lines of magnetic force there will be a current generated in the wire that goes to make up the coil. Furthermore, if this coil is wound about a piece of soft iron known as a core, and the core revolved between the two magnetic poles so that magnet-

ism passes through the core one instant and not the next, then more electricity will be generated. The core offers an easy path for the magnetism. Soft iron is used for the core because it can very quickly become magnetized, and what is just as important it will quickly give up its magnetism. By revolving such a core between the poles of a horseshoe magnet, it will amount to successively plunging a magnet in a coil and rapidly drawing it out again. The magnetic lines of force from the core, when it is magnetized, will of course be cut by the coil which accounts for the current.

As the core is revolved between the two magnetic poles, which are distinguished by calling one the North pole and the other the South pole, the core is magnetized when in a horizontal position almost connecting the two poles and demagnetized when it has turned 90 degrees to a vertical position. Consequently in one complete revolution of the core it will be magnetized twice and demagnetized twice. It so happens that a little more current is generated in the coil when the core loses its magnetism than when it receives its magnetism, which means that maximum current is obtained when the core is approximately in a



DIAGRAMS TO ILLUSTRATE THE LOCATION OF THE CORE IN A SHUTTLE TYPE MAGNETO

vertical position. Since it is in this position twice during one complete revolution, it follows that an ordinary magneto furnishes two sparks per revolution.

So far the core has been considered as the revolving part. Identically the same result is obtained when the core is held stationary and the magnet or magnets are revolved. To turn the magnets is inconvenient on account of their horseshoe shape, so rotating poles are often used to accomplish the same result. This is referred to as a revolving field. In the first case where the core is rotated, an armature made up of the core and the shaft that carries it is used. In appearance the armature has somewhat of a resemblance to a shuttle, on account of the windings about the core. For this reason the type of magneto using the revolving core and coil is called the shuttle type, while the one in which the magnetic field revolves and the coil remains stationary is known as the inductor type. More attention will be devoted to the inductor type after the shuttle type has been further explained.

The current required to jump the gap between the points of a spark plug under high compression is much greater than the amount

supplied by a single coil wound about a core. In order to have a self-contained unit it is necessary to make use of another coil wound about the first consisting of much finer wire and having several hundred times as many turns as in the first coil. The coil wound nearest the core is called the primary coil, while the outside one is the secondary coil. Now if we have some automatic device to break the path of the current from the primary coil at the same time that the core loses its magnetic charge a high tension current will be induced into the secondary coil and will be suitable to conduct to the spark plugs. The principle is that of a transformer.

On the shuttle type magneto a breaker mechanism through which the primary current passes is held on one end of the armature, causing it to be revolved at exactly the same speed as the armature is turning. Cams on the breaker housing force the breaker points to separate for an instant, at the same time that the core loses its magnetism. All that is necessary to do in order to stop the magneto from delivering current and in turn stop the engine is to close a switch on a line that connects the two breaker points. This will short circuit

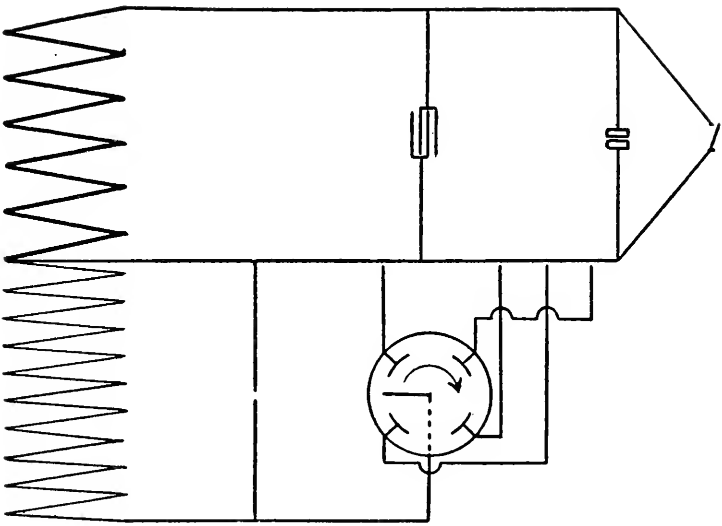
the primary, destroying the effectiveness of the breaker points and prevent the primary from inducing any current into the secondary coil.

To advance or retard the spark, the position of the breaker cams is changed. This affects the time that the primary circuit is broken. Moving the cams with the direction of rotation retards the spark, while to advance the spark the cams are moved against the direction of rotation. This brings us to one difficulty with the shuttle type magneto. In order to get the maximum current the primary circuit should be broken as the core loses its magnetic charge. If the spark is retarded, however, the primary is broken a little later than the magnetic lines of force are broken, which results in a weaker spark. The effect is frequently to hinder starting as it is necessary to retard the spark to prevent injuring the one who is cranking.

In the primary circuit a condenser is placed in multiple with the breaker points. It consists of alternate sheets of a conductor and a non-conductor such as tinfoil and mica. Half of the sheets of the conductor are attached to one terminal, and the other half are attached to the second terminal. This provides a place for the current to go momentarily after the

breaker points have separated. If a condenser were not used there would be a tendency for the current to continue flowing for an instant through the air between the separating points, which would result in arcing and pitting the points. Right here it should be noted that the breaker points are of platinum and should not separate more than .020 inch. Since the condenser prevents arcing it also serves to make the break in the primary circuit occur more quickly, which means that more voltage will be induced into the secondary coil.

As a means of conducting the secondary current to the right spark plug at the right time a distributor is used. It consists of as many segments as the number of spark plugs that the magneto supplies. A distributor arm with a carbon brush directly connected with the secondary coil turns about upon the distributor plate conducting secondary current to each segment in turn. With the spark fully advanced, the distributor arm should just be entering a segment every time the breaker points separate. For convenience the primary and secondary circuits are both grounded. Should the secondary circuit be left open, as would be the case if a wire were not attached



WIRING DIAGRAM OF A MAGNETO SYSTEM

to a spark plug, the result might be that the high pressure of the secondary would cause a short circuit between the two coils. To avoid such a happening a safety gap is provided in the secondary circuit. Its points are generally three-eighths of an inch apart insuring no interference with sparking at the plugs.

The electrical pressure is expressed in volts. The flow is expressed in amperes. One volt times one ampere is equivalent to one watt, which is nothing more than a unit of work, being 1/764 part of a horse-power. The wattage of an ordinary magneto is about twenty. The voltage in the primary circuit is from six to ten volts, while that in the secondary is about ten thousand. The amperage of the primary is limited to only a few amperes, yet that of the secondary is infinitely less, being only the slightest fraction of an ampere, for it should be remembered that when a current of higher voltage is obtained by induction the gain in the number of volts will be accompanied by a loss in the number of amperes. Upon the speed of the armature and the number of windings depends the voltage of a magneto. The number of amperes is dependent upon the strength of the magnets.

An ordinary magneto can deliver but two sparks per revolution, so the speed of the armature is governed by the number of explosions in the engine during one complete cycle. A four-cylinder engine will fire four times in two revolutions or two times in one revolution. Since two sparks will then be necessary for every revolution of the crank shaft, it follows that the armature should turn at engine speed. In an eight-cylinder engine there will be four explosions per revolution, so the armature will have to turn at twice engine speed to give the four sparks at the right time. The speed of an armature on a magneto supplying twelve cylinders would be three times engine speed. A convenient means of determining this relative speed is to divide the number of cylinders by four. The distributor arm turns at camshaft speed owing to the fact that each cylinder requires one spark in two revolutions of the engine.

The Dixie magneto, which is a good example of the inductor type, has been widely used and deserves consideration. In it the magnets are turned at right angles to the position that they occupy in the Bosch and Berling, which are representatives of the shuttle type. A shaft

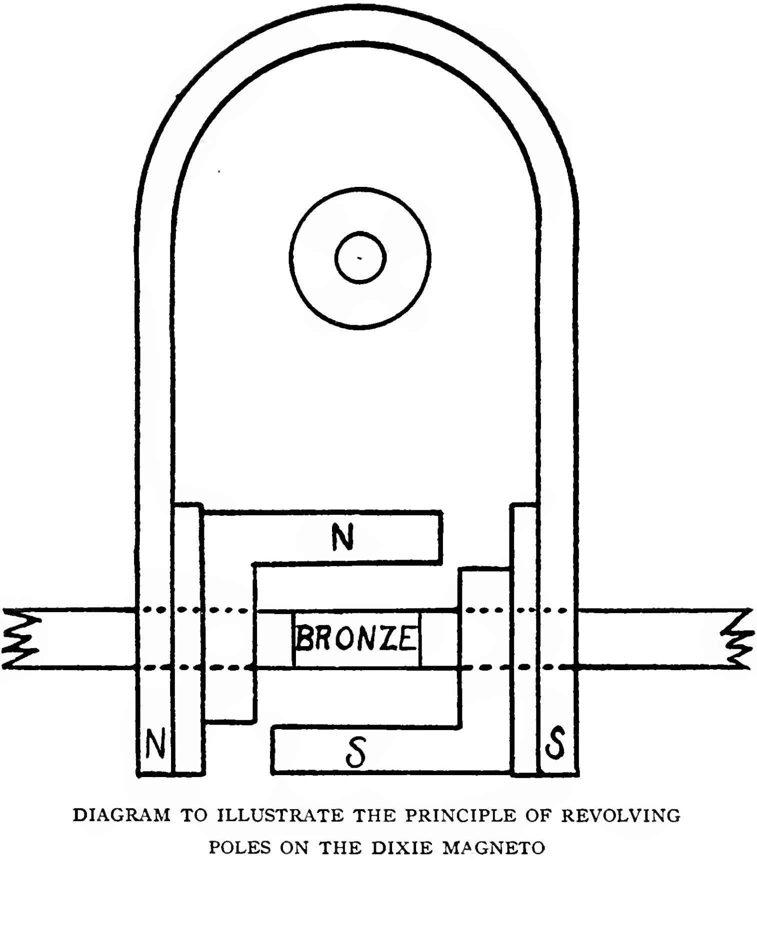


DIAGRAM TO ILLUSTRATE THE PRINCIPLE OF REVOLVING POLES ON THE DIXIE MAGNETO

carrying two shoes or pole extensions separated by a bronze block is placed in line with the two poles of the magnets. This shaft having no windings upon it is not called an armature, but is known as a rotor. As the rotor is revolved the shoes, each being in contact with one pole and being separated by the non-magnetic bronze, will always have their respective magnetic charges, and the effect will be much the same as though the magnets themselves were revolved. Were it not for the bronze between the two shoes there would be a direct flow of magnetism through the rotor between the two poles, and the shoes would then be useless.

At right angles to the rotor is placed the core carrying the primary and secondary coils. It is located in the space between the rotor and the top of the magnets. Extending downward from both ends of the core are two bars of soft iron known as field pieces, and it is between these two field pieces that the shoes revolve. When the shoes are in a horizontal position, magnetism will pass from one shoe into the nearest field piece, then through the core, into the other field piece, and thence into the opposite shoe. When the shoes move to a vertical

position the core will receive no magnetism, but in moving another 90 degrees the shoes will come again to a horizontal position, and magnetism will pass through the core in a reversed direction. Thus the core will be magnetically charged one instant and not the next, resulting in the generating of electricity.

The breaker assembly does not revolve on the end of the rotor, but is worked by cams on the end of the rotor shaft. To advance or retard the spark it is thus possible to move the whole breaker assembly instead of changing the position of fixed cams, as is done on the shuttle type. Since the coils and core do not revolve, it is also possible to change the position of the core and field pieces with the changing of the position of the breakers. The result is to break the magnetism in the core with the breaking of the primary circuit even though the spark is fully retarded. This insures the same intensity of spark when cranking the engine as is obtained at top speed with the spark fully advanced.

A special type of Dixie magneto is one having four shoes instead of two. There are two opposite North shoes and two opposite South shoes. The two field pieces leading to the core

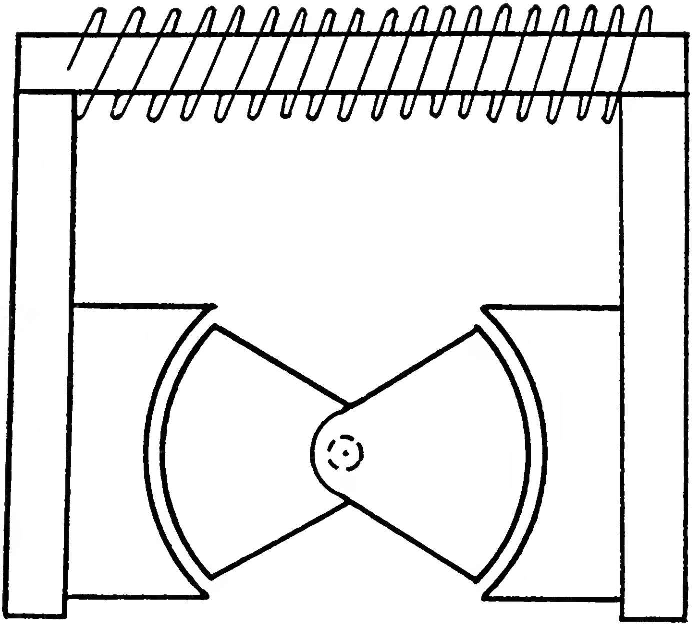


DIAGRAM TO ILLUSTRATE POSITION OF ROTOR IN THE DIXIE MAGNETO WHEN THE CORE IS MAGNETIZED

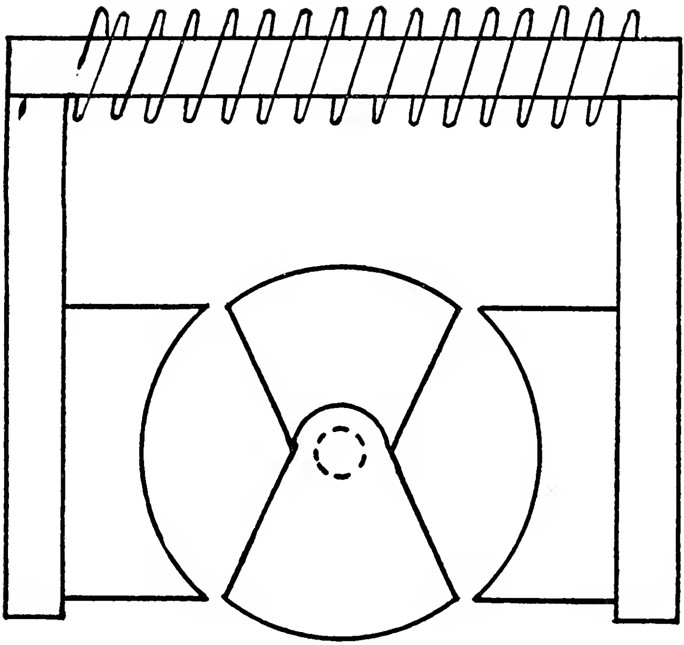


DIAGRAM TO ILLUSTRATE POSITION OF ROTOR IN THE DIXIE MAGNETO WHEN THE CORE IS DEMAGNETIZED

are shortened so that their ends will be well above the center of the rotor to allow unlike shoes to connect the two ends. Since the opposite shoes have the same polarity, it would not do to have the ends of the field pieces in line with opposite shoes. The advantage of this type of Dixie is that four sparks can be secured during one revolution of the rotor, which permits a much slower running magneto on an engine having a large number of cylinders.

The magnets themselves deserve attention. They are made of hard steel in order to retain their magnetism as long as possible. To recharge a magnet it is simply necessary to wind it with insulated wire and pass direct current through the wire. When dismounted from the magneto it is necessary to provide a path for the magnetism between the two poles. A strip of steel will answer for a keeper, or the unlike poles of two magnets may be placed together, insuring a perfect magnetic circuit.

In timing a magneto to an engine it is best to start by selecting a cylinder and placing the piston in that cylinder in the right position on the compression stroke for the spark to occur. Then turn the distributor arm so that it is about to enter the segment which has connec-

tion with the spark plug in the selected cylinder. Next, after making sure the spark lever is fully advanced, turn the magneto in its right direction until the breaker points have just separated. The distributor arm should now be upon the foremost part of the segment to insure that it will still be in contact with the segment when the spark lever is retarded. The remaining step is to connect the driving shaft with the armature or rotor as the case may be. Upon those engines having double ignition to procure a greater factor of safety and to reduce the time to fully explode the charge, the two magnetos must furnish their sparks at the same time or be synchronized as it is technically called. To accomplish this the first magneto is timed to the engine and the second magneto is timed to the first. In this way the breaker points on each one can be made to separate at the same instant.

With a battery system either a vibrating or a non-vibrating coil may be used. Vibrating coils will give a rapid succession of sparks at the spark plugs. The primary circuit is made to pass through the vibrator and the magnetism in core is allowed to separate the vibrator points which breaks the primary circuit and

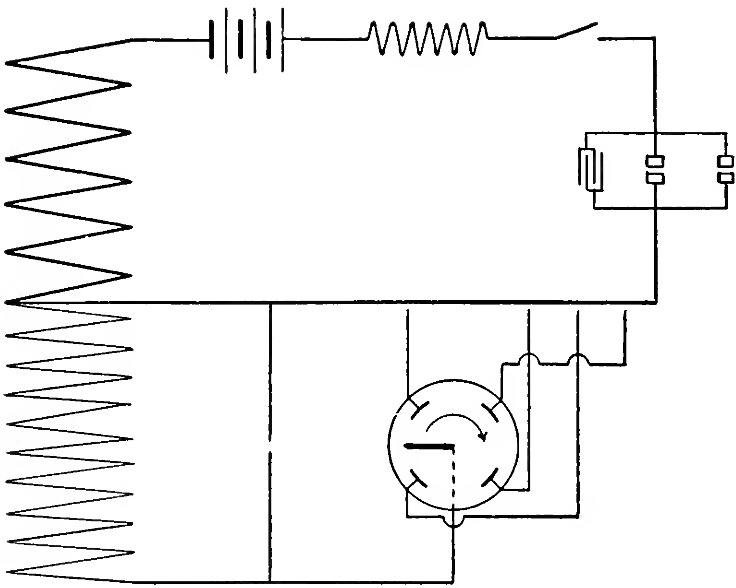


DIAGRAM OF A BATTERY SYSTEM OF IGNITION
WITH A NON VIBRATING COIL

demagnetizes the core. The contact is then made again by the vibrator springing back and the operation is repeated. When a non-vibrating coil is used there must be mechanically-operated breakers to break the primary circuit, very similar to those used on magnetos.

The wiring diagram for a battery system using mechanically-operated breakers is similar to a magneto wiring diagram, except that the switch is not placed in the same position. In a battery system the switch is placed in series in the primary circuit, and by opening the switch the engine is stopped. Sometimes two breakers are used instead of a single one. The two are then wired in multiple and are made to break at the same time, thereby insuring uninterrupted flight in case one refuses to close. A small resistance coil of iron wire is often placed in the primary circuit with a view to saving the battery during slow running, or in case the switch is left closed when the engine is not running. Ordinarily when the engine stops the breaker points are together, which, with a closed switch, affords a direct path for the current to pass from one pole of the battery to the other. The iron coil will then be heated with the result that less

current can pass through the heated iron wire than when it was cold. In this way a battery will not be exhausted so readily. A coil that serves this purpose is called a ballast coil.

CHAPTER VII
LUBRICATION

THE PURPOSE of lubrication is to reduce friction. Even though two pieces of metal that move one upon the other may have their surfaces highly polished and appear perfectly smooth, it will be noticed upon examination with a microscope that the surfaces are very irregular. In other words all sliding surfaces, no matter how carefully they may be finished, are known to consist of minute projections and depressions. Consequently the projections and hollows on the contact faces tend to interlock and resist a sliding motion. From this it can readily be seen that friction is nothing more than the force which resists the relative motion of one body in contact with another body. Excessive friction results in the development of heat.

As a means of minimizing friction, oil is introduced between the contact surfaces. The oil will first fill the depressions and finally form a film between the two surfaces, separating them sufficiently to prevent the projections on one surface from interlocking with the de-

pressions on the other. This is referred to as the theory of lubrication. Perfect lubrication is greatly to be desired for it eliminates wear, and by reducing the power required to turn the engine it adds to the efficiency of an engine.

After realizing the necessity for oil the next step is to ascertain what properties an oil must have in order that it may be suitable for aviation engines. In testing an oil it is customary to determine the gravity, viscosity, flash point, fire point, and whether or not it has acid properties.

The gravity of an oil has in reality no effect upon its lubricating merits, as there is considerable variation in the gravity of high grade oils. However, it is usually determined and used principally in checking current deliveries of a certain brand. The specific gravity is the ratio between its weight and the weight of an equal volume of water. In the oil trade, though, it is customary to use the Baume gravity scale in which the gravity of water is 10 at 60° F. The lighter the oil is in body, the higher will be the Baumé reading. Hydrometers graduated for either specific gravity or Baumé are used to measure the gravity of an oil. The following formula will serve to convert one scale in another:

Specific gravity $=\frac{140}{130+\text{Baumé reading}}$.

Viscosity is the technical name for what is popularly called "body." To express it more specifically it is the fluidity of an oil. To obtain the viscosity the oil is put into a cup surrounded by water at about 212° F. When the oil has reached this temperature, a plug of specific size in the bottom of the cup is removed allowing 60 c.c. of the hot oil to run out into a marked flask. The number of seconds required to draw the 60 c.c. is reported as the viscosity of the oil. Good cylinder oil will have a viscosity of about 75 seconds.

The flash point is the lowest temperature at which the oil will ignite but not continue to burn. If the flash point is too low, the oil will not remain on the cylinder walls and bearings when the normal heat is developed, leaving the friction surfaces without lubrication. It is well to use oil having a flash point above 325° F.

The fire point is the temperature at which the ignited vapor from the oil will continue to burn. This temperature, which ranges between 45° and 75° F above the flash point, is not of much consequence from our standpoint as it is always beyond the point where the oil will cease to be useful.

Certain mineral oils are treated with sulphuric acid during the process of refinement. To protect the highly polished bearing surfaces it may be necessary to ascertain if any acid has remained in the oil. A simple way of testing is to wash a sample of the oil with warm water and test the water with litmus paper. The presence of any acid will result in the paper being turned pink.

Lubricating oil we are accustomed to think of as being only mineral oil. With the development of aviation engines, castor oil, which is a vegetable oil, has received considerable attention. This oil, which has a gravity of 96° Baumé and a flash point a little higher than most mineral oils, will thicken to a marked degree upon standing. When heated it will readily oxidize and exhibit acid properties, rendering it of little use in engines where the oil is used over and over again. Its universal use in rotary engines is due to the fact that it will not unite with gasoline. In these engines the crank case is filled with gasoline vapor which tends to wash off any mineral oil that is supplied to the bearings. Hence castor oil is resorted to, and as long as the oil is used but once in rotary engines, it serves very well as a lubricant.

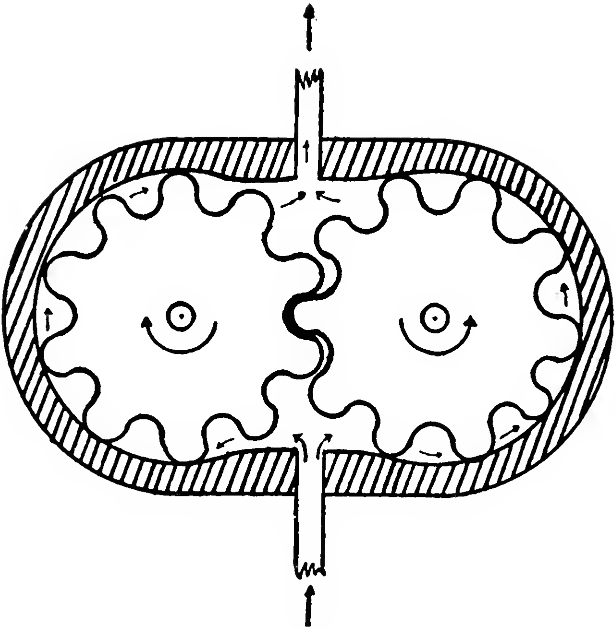
Very few engines have the same system of lubrication. The oil supply is generally carried in the lower half of the crank case which is called the sump. Frequently auxiliary tanks having connection with the sump are used. The splash system of oiling is not suitable for aviation engines, so it is possible to make use of what is called a dry sump. If no provision is made to retain the oil in the sump when an engine is momentarily inverted there is great danger of the oil rushing into the cylinder and piston cavities. However, if the lower half of the crank case has a false bottom the oil may be carried in the compartment thus formed with no danger of it rushing out. Another way to obtain a dry sump is to collect the returning oil from the bearings in a trap at the bottom of the crank case and pump it away to a tank where the main supply is located.

A gear pump is generally used to force the oil to the bearings. Its construction is remarkably simple as it consists of two rotating gears in a closely-fitted housing. Oil is caught in the spaces between the successive teeth of each gear and carried around to the discharge of the pump. Plunger pumps and vane pumps are also used. The Hispano-Suiza engine makes

use of the vane pump to develop a high oil pressure.

A pressure relief valve is usually placed on the oil line very near the pump. Such a valve consists essentially of a poppet valve which opens outwardly and which is held in place by a spring fitted with a cap screw. In case the line were to become obstructed, the valve will open relieving the pressure and permitting the oil to return to the sump. By changing the tension of the spring with the cap screw the oil pressure may be regulated. A sight gage in the cock pit is used to indicate the pressure. It should be connected to the main oil line at a point not far distant from the pump. When plunger pumps are used, pulsators are often employed to show the operation of the pumps. A pulsator consists of a glass dome in which a quantity of air is compressed by the entrance of some oil from the main oil line. The impulses of the plunger in the pump will give rise to a throbbing motion of the surface of oil in the glass dome.

While the oiling system in the Curtiss OX can not be regarded as representing the way all aviation engines are oiled, it may be well to describe it and point out its peculiarities. In



GEAR PUMP

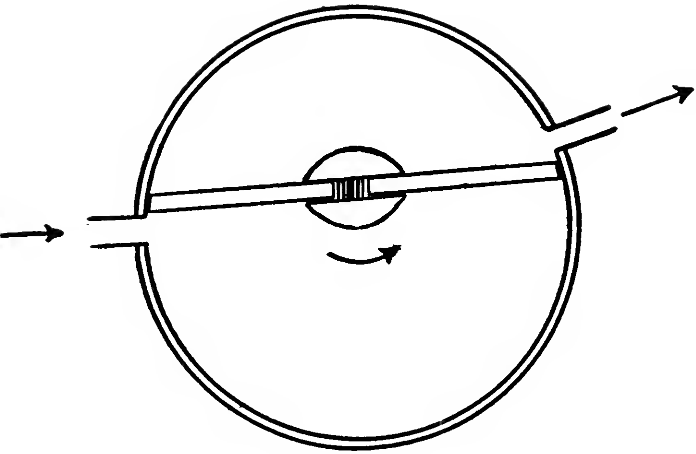


DIAGRAM TO ILLUSTRATE THE OPERATION OF A VANE PUMP

this engine the oil is carried in the sump where it is covered with splash pans. Toward the propeller end of the sump is located a gear pump which forces the oil under a pressure of about fifty pounds to the propeller end of the hollow cam shaft. At each of the five cam-shaft bearings a hole is drilled allowing oil to escape and oil these bearings. Directly beneath each cam-shaft bearing is a crank-shaft bearing. The partitions in the crank case or webs as they are called, which connect the cam-shaft bearings with the crank-shaft bearings, are drilled. In this way oil is supplied to grooves in the cam-shaft bearings, whence it is forced down the holes in the webs to the crank-shaft bearings. Radially-drilled holes in the hollow crank shaft at each of the five main bearings allow oil to pass once in each revolution from the holes in the crank case webs into the crank shaft. Centrifugal force carries it out the crank-shaft throws. Each crank pin has two holes drilled in that part of the pin directly away from the center of rotation. In this way centrifugal force carries oil out of the crank pins to oil the two lower connecting-rod bearings upon each crank pin. The seepage from these bearings develops a spray of oil

within the crank case. As a piston moves upward, exposing part of the cylinder wall, the spray comes in contact with the wall and oils it. Also the spray is made use of to oil the wrist-pin bearings in the piston bosses by allowing it to enter holes drilled in the bosses. Since the cam shaft is located within the crank case in this engine the cam surfaces will be oiled by the spray. The magneto gear and cam shaft gear are oiled by spray from a hole in the retaining screw of the cam-shaft gear. The thrust bearing receives what little oil it requires from a small hole in the crank shaft near this bearing. The most peculiar feature of the system is that the cam shaft is used as a main distributing line. A crank shaft hollow throughout is another striking feature.

Some aviation engines are equipped with cooling devices for the oil. Their object is to maintain a suitable viscosity and also a slight cooling effect upon the bearings. The Hall-Scott engine makes use of an oil-cooling jacket very near the carburetor on the intake manifold. Owing to the fact that vaporization is accompanied by the extraction of heat from surrounding bodies, the oil is cooled by the vaporizing of gasoline. The Thomas-Morse

engine passes its oil through a coil of pipe known as an oil radiator which is located in a sufficiently cool place. An auxiliary oil tank is used in connection with the Sturtevant engine. By passing the oil to and from the tank a lowering in temperature is secured. Another method used on some foreign engines is to pass air tubes through the sump, and, by drawing air through these tubes to the carburetor, a cooling effect upon the oil in the sump will be gained.

CHAPTER VIII
COOLING

A RAPID succession of explosions within a cylinder would soon heat its interior to redness if some means were not taken to conduct the heat away. Such high temperature would burn the lubricating oil and cause the pistons to seize and the bearings to burn out. Excessive heat will also cause irregularities in the combustion chamber to become so highly heated that they will ignite a fresh charge of gas. Obviously some of the heat must be conducted away. A great danger comes into account at this point, because it often happens that too much heat is removed. If the cylinder is too cool the pressure of the gas expanding during a power stroke will be lessened by a large amount of its heat entering the cylinder wall, for it will be remembered that the pressure exerted by a gas is governed largely by temperature. From this it can be seen that there is a great necessity for cooling, but to get the maximum efficiency from an engine it likewise is necessary to avoid over cooling.

Heat may be conducted from a cylinder by

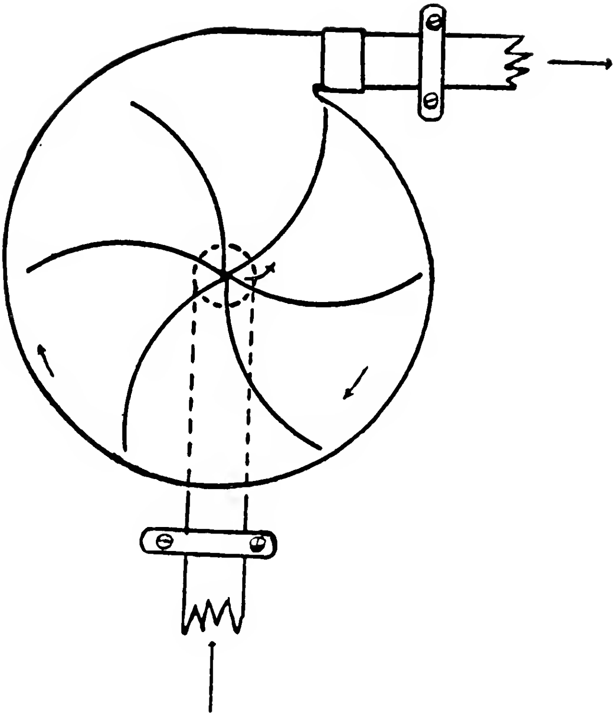
water or by air. Fixed-cylinder engines with one or two exceptions are always water cooled, while rotary engines are invariably air cooled. The advantages in air cooling are a decrease in weight and the avoidance of a circulating system that can be pierced by bullets. However, uniform cooling can best be accomplished by water. The most important point to note regarding air-cooled engines is that the cylinders are supplied with cooling flanges which increase the surface from which the heat may be radiated.

Water-cooled engines make use of a radiator, usually cellular though sometimes tubular in construction, and water jackets upon the cylinders. Water is supplied to the base of the jackets and moves upward over the heads of cylinders. At the top of each cylinder it is conducted to the top of the radiator where it is cooled and consequently tends to move toward the base of the radiator. From this point the relatively cool water is drawn to the pump which delivers it to the water jackets to be heated again. In this way the water is circulated by the pump in the same direction that the constant heating and cooling would cause it to travel. A thermosyphon system would be

one depending wholly upon automatic circulation from this source. Oftentimes to prevent condensation within the intake manifold a little of the hot water that is about to enter the top of the radiator is led through a jacket on the manifold and from there to the intake of the pump.

The type of water pump used on aviation engines is with few exceptions the centrifugal pump. In cases where these are not used the gear pump is employed. In a centrifugal pump the water is led into the center of a circular chamber in which revolve several blades on a common shaft. A whirling motion of the water is secured enabling it to be led away at a tangent to the circular chamber under pressure. One advantage of a centrifugal pump over a gear pump is that the water may circulate through the pump after it has stopped operating. When a gear pump ceases to operate the water system is blocked.

Hose connections are used on the water lines between the engine and the radiator. These prevent many of the vibrations of the engine from reaching the radiator. In making hose connections, especially on the line leading to the intake of the pump, care should be taken



CENTRIFUGAL PUMP

not to have more than one and one-half inches of hose exposed to the water, as there is danger of the hose weakening and lessening the flow by its being drawn together.

When a plane is to be used in winter weather or when it is required to fly at a great altitude, anti-freezing mixtures may be used. The best one consists of 17 per cent alcohol, 17 per cent glycerine, and 66 per cent water. Such a mixture will be suitable at a temperature as low as 15° below zero. Although this mixture is far superior to salt solutions it is not perfectly satisfactory, because after being heated there is always an uncertainty as to the quantity of alcohol.

CHAPTER IX
ROTARY ENGINES

A ROTARY engine is one in which the cylinders and crank case revolve about a stationary crank shaft. The common type is that having the cylinders placed in the same plane and radiating at equal intervals from a common center. The center of rotation is the center of the crank shaft. By placing all the cylinders in the same vertical plane a crank shaft of only one throw can be used, which means a centralizing of the forces exerted upon the crank shaft. With the throw placed vertically upward, the pistons will reach top center when their respective cylinders are directly above the single crank pin. If an explosion occurs within a cylinder when it is at top position the effect will be to increase the combustion space by revolving the cylinder farther away from the crank pin, which allows the piston to move away from the cylinder head. The force that revolves the cylinder is the force exerted by the piston upon the cylinder wall.

Considering that the cylinders revolve instead of the crank shaft, it will at once be ap-

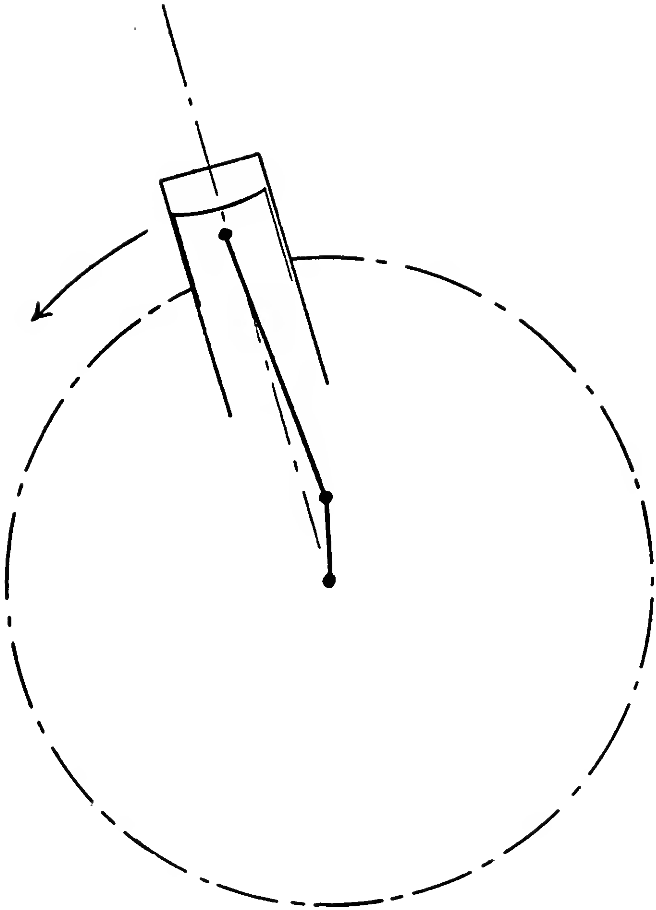


DIAGRAM TO ILLUSTRATE THE PRINCIPLE
OF A ROTARY ENGINE

parent that rotary engines will differ from fixed cylinder engines in the manner of support, the way the cylinders are retained, the way the gasoline mixture is supplied to the cylinders, the way the valves are operated, and the way electricity is made to reach the spark plugs.

Briefly, rotary engines are supported by two plates holding the rear end of the crank shaft which allows the engine to overhang its support. The plate nearest the engines, which carries the magnetos and pumps is called the bearer plate. The rear one is the centralizing plate. The cylinders are retained by screwing them into the crank case and locking them with a lock nut, or by having the crank case made in two parts and clamping their flanged bases between the two halves of the crank case. In rotary engines the crank case is used to store the gas which is conducted to the cylinder either by means of ports in the cylinder wall or by individual manifolds from the crank case to the intake valves in the heads of the cylinders. The valves are operated by rods and rocker arms with sometimes an attempt to fulcrum the rocker arm at such a point that the centrifugal force acting upon the rod will be

counterbalanced by that acting upon the rocker arm and the valve. Cam plates or cam packs revolving on the stationary crank shaft are used to operate the rods. Electricity is led to the spark plugs by means of bare brass wires drawn taut to segments imbedded in the revolving thrust plate. A stationary brush protruding through the bearer plate has connection with the magneto and comes in contact with each segment as the engine revolves.

The demand for increased power has led to the design of rotary engines with an additional bank of cylinders behind the first bank. The same general construction is used except that a crank shaft of two throws must be used with this type of engine. Those having one bank always have an odd number of cylinders while the two-bank engines have an even number. However, this even number is occasioned by an odd number of cylinders being on each of the two banks. The reason for an odd number of cylinders is to allow for an equal spacing of the power impulses. These engines, being four-stroke cycle engines, will have all cylinders function once in two revolutions. By using an odd number it is possible to fire alternate cylinders as they come to top position, which

results in all cylinders having a chance to work once during two revolutions and still allow another cycle to be started without any interruption. The cylinders are numbered in a clockwise direction viewed from the propeller end.

While rotary engines are made almost entirely of steel, as a general rule they develop much more power for their weight than fixed-cylinder engines. This is due largely to the short crank shaft, the short crank case, and the fact that they are air cooled instead of water cooled. On account of the difficulty in supplying the revolving cylinders with gas, these engines use much more fuel proportionately than do fixed-cylinder engines. Due to their light weight they have become very popular for speed scout work, where brief but rapid flights are necessary. For great distances they are not looked upon with much favor because of the great quantity of fuel that must be carried to answer the engine's needs. For stunt flying rotary engines are admirably suited, on account of their ability to work perfectly in any position. In any comparison of rotary and fixed-cylinder engines it must not be lost sight of that rotary engines, due to their radial form,

offer the more head resistance. It is difficult to meet the demand for increased power with rotary type engines except in those cases where two-bank engines are used. An attempt to lengthen the stroke results in longer cylinders, which means more centrifugal force will be developed. The bore has limitations, because the sum of the diameters of the cylinders must be approximately the same as the circumference of the crank case. The compression can not be greatly increased, because the resulting increase in temperature is more than can be satisfactorily cared for by air cooling.

The Gnome "monosoupape" is a well-known rotary engine which has attracted wide attention. It is made in two sizes having one and two banks of cylinders. The nine-cylinder engine is the 100 H.P. Gnome, while the eighteen-cylinder one is the 180 H.P. Except for the number of cylinders the two engines are very similar. In entering into a description it is sufficient to take up the nine-cylinder engine.

In any rotary engine great pains must be taken to prevent centrifugal force from carrying the cylinders away. In the nine-cylinder Gnome the crank case is split into two circular halves, and the cylinders are clamped between

the two parts. The cylinders, which are machined from billets of steel, are drilled so that a ring of small ports is located near the base of each cylinder. These serve as an inlet valve, for, as a piston goes to bottom center, the ports are uncovered and direct connection is made between the interior of the crank case and the space beyond the piston head. The head of the cylinder is supplied with a large exhaust valve which gives rise to the name "monosoupape," French for single valve.

The valve timing is novel inasmuch as it is a four-stroke cycle engine using a two-stroke cycle method of admitting the charge. The spark occurs 18° of the engine's rotation before top center. The power stroke is interrupted 85° past top center by the opening of the exhaust valve. This valve remains open 395° or 120° past top center, allowing all the burned gas to be expelled and a supply of air to be drawn in during the 120° it remains open while the piston is going down. After the exhaust valve is closed the downward motion of the piston tends to create a partial vacuum within the cylinder so that when the intake ports are uncovered 20° before bottom center, a very rich mixture that is stored in the crank case

will rush into the cylinder. The gas enters during the 40° that the ports are uncovered and mixes with the air that has been drawn in through the exhaust valve. A suitable mixture is thus formed which is compressed and ignited 18° before top center. The reason for the early opening of the exhaust valve is to secure the same pressure within the cylinder as that within the crank case when the intake ports are uncovered on the power stroke.

The rich mixture held in the crank case is formed by gasoline being sprayed from a nozzle connected to the pipe that extends within the hollow crank shaft. The gasoline which is under a pressure of five pounds is led through a shut-off valve located in the cock pit for the pilot to control. Obviously the range of speed is greatly limited by this means of control, because too lean a mixture is apt to result in back-firing and ruining the engine. A safer way to reduce the speed is to make the mixture too rich.

Electricity is supplied to the spark plugs by a high-tension magneto located on the bearer plate, with a stationary brush bearing upon the segments that revolve at engine speed. The magneto must turn two and one-fourth

times engine speed since this is a four-stroke cycle engine of nine cylinders. Due to the fact that an ordinary magneto supplies but two sparks per revolution the magneto does not furnish a spark every time the brush is on a segment, but with a 2¼ gearing it is capable of furnishing sparks for alternate segments. This is what is needed to obtain the right firing order.

The connecting rods are made to work upon a hub that revolves upon the crank pin. One connecting rod called the master rod, is made integral with the hub to maintain its proper rate of rotation. The eight other connecting rods are pinned to the hub. The master connecting rod prevents the lower ends of the connecting rods from moving too far from their respective cylinders. In order that the hub may be mounted upon the crank pin it is necessary for the crank shaft to be made in two pieces. From this it follows that the crank shaft will be weakened so that the thrust of the propeller must be transmitted through the crank case to a thrust bearing at the rear of the engine.

The pistons of the Gnome engine are made of cast iron with the piston bosses attached to

the concave piston head. The trailing edges of the skirts are cut away to prevent piston interference. The surface on the leading edge is not reduced as it will be remembered that it is the force of the piston against the cylinder wall that causes the engine to turn. On account of the leading edge of a cylinder coming in contact with more air than the trailing edge, the expansion of a cylinder will be slightly irregular. This makes necessary a compression ring that will conform to the irregularity. A flexible L-shaped bronze ring known as an "obturator" is used. This ring is retained in a groove very near the piston head by means of a steel packing ring. The gap in the "obturator" is placed on the leading edge where there is the least amount of clearance. The piston is also supplied with a cast-iron oiling ring.

The exhaust valves are operated by rocker arms and push rods, which, with the tappets, radiate spirally from the cam pack located at the propeller end of the engine. The nine cams on the cam pack are designed with 197½° faces on account of the exhaust valve being held open for 395°. The cam pack is made to turn on the stationary crank shaft at half engine speed by a system of six planetary

gears. A thirty-tooth gear held rigidly upon the crank shaft meshes with two thirty-tooth gears pinned to the crank case. Each of the revolving thirty-tooth gears has a twenty-tooth gear secured rigidly to it, and it is the twenty-tooth gears that mesh with one having forty teeth attached to the cam pack. The reduction of two to one is thus secured.

Castor oil is delivered to two tubes within the crank shaft by a double plunger pump located upon the bearer plate. Pulsators are used to indicate the operations of the pumps. The oil from one tube goes to lubricate the front and rear bearings and the cam pack. The oil from the second tube is used to oil the connecting rod assembly and wrist pins. Spray from the connecting rod assembly comes in contact with the cylinder walls. Centrifugal force which carries the oil out the exhaust valves prevents the use of a circulating system. Due to oil being carried toward the cylinder head, it is impractical to place the spark plugs in the head. They are placed on the leading edge where they are less likely to become fouled.

The Le Rhone engine with its threaded cylinders and peculiar valve operation has

attracted a great deal of attention. Gas is supplied to the crank case by a crude carburetor attached to the rear end of the hollow crank shaft. A throttle and metering pin are used in the carburetor allowing a slightly wider range of speed than can be obtained with the Gnome. The inlet valve being located in the cylinder head, a separate manifold is used to conduct the gas from the crank case to each cylinder.

The cylinders are of steel, and, being threaded at the base, they are retained by being screwed into the crank case and locked with a large lock nut. This design permits the compression to be changed by screwing the cylinders in or out as the case may be. A cast-iron liner shrunk into each cylinder does much to prevent irregular expansion from interfering with the piston rings. No "obturator" is used on the Le Rhone.

The inlet and the exhaust valves located in the cylinder head are operated by a single rod for each cylinder. A rocker arm is attached to each end of the rod. The base rocker arm is fulcrumed to the crank case with both ends supplied with rollers, each bearing upon a separate cam plate. These cam plates have five cams upon each one and are so constructed

that when one end of the rocker arm is forced up by one plate the other end sinks into a depression on the second plate. In this way the rod is used both as a push rod to open the exhaust valve and a pull rod to open the inlet valve. Since each cam plate has five cams they are revolved at nine-tenths engine speed. This rate is necessary because the valves must open nine times in two revolutions of the engine, and in two revolutions of the cam pack ten cams come into position.

The connecting rods are designed with shoes at their large ends. The hub on the crank pin is made up of two discs each having three grooves to receive the connecting rod shoes. The discs are clamped together and hold the connecting rods between them. Each groove holds three shoes, and being a nine-cylinder engine, it follows that the connecting rods will be of three lengths. With this construction no master rod is necessary.

CHAPTER X
THE LIBERTY MOTOR

THE LIBERTY MOTOR, which represents the latest development in aviation engines, is not known in detail by many at present. Due to the discretion of the War Department, little if anything could be learned regarding it during the time that the first engines were being built and tested. Now that its success is assured, the Committee on Public Information has given the writer permission to print the facts set forth in a recent number of "The Official Bulletin." The following paragraphs are authorized by the War Department and the Committee on Public Information:

"The designs of the parts of the Liberty engine were based on the following:

"Cylinders.—The designers of the cylinders for the Liberty engine followed the practice used in the German Mercedes, English Rolls Royce, French Lorraine, Dietrich, and Italian Isotta Fraschini before the war and during the war. The cylinders are made of steel inner shells surrounded by pressed-steel water jackets. The Packard Co. by long experiment had

developed a method of applying these steel water jackets.

"The valve cages are drop forgings welded into the cylinder head. The principal departure from European practices is in the location of the holding-down flange, which is several inches above the mouth of the cylinder, and the unique method of manufacture evolved by the Ford Co. The output is now approximately 1,700 cylinder forgings per day.

"Cam shaft and valve mechanism above cylinder heads.—The design of the above is based on the Mercedes, but was improved for automatic lubrication without wasting oil by the Packard Motor Car Co.

"Cam-shaft drive.—The cam-shaft drive was copied almost entirely from the Hall-Scott motor; in fact, several of the gears used in the first sample engines were supplied by the Hall-Scott Motor Car Co. This type of drive is used by Mercedes, Hispano-Suiza, and others.

"Angle between cylinders.—In the Liberty the included angle between the cylinders is 45°; in all other existing twelve-cylinder engines it is 60°. This feature is new with the Liberty engine, and was adopted for the purpose of bringing each row of cylinders nearer

the vertical and closer together, so as to save width and head resistance. By the narrow angle greater strength is given to the crank case and vibration is reduced.

"Electric generator and ignition.—A Delco ignition system is used. It was especially designed for the Liberty engine to save weight and to meet the special conditions due to firing twelve cylinders with an included angle of 45°.

"Pistons.—The pistons of the Liberty engine are of Hall-Scott design.

"Connecting rods.—Forked or straddle-type connecting rods, first used on the French De Dion car and on the Cadillac motor car in this country, are used.

"Crank shaft.—Crank shaft design followed the standard twelve-cylinder practice, except as to oiling. Crank case follows standard practice. The 45° angle and the flange location on the cylinders made possible a very strong box section.

"Lubrication.—The first system of lubrication followed the German practice of using one pump to keep the crank case empty, delivering into an outside reservoir, and another pump to force oil under pressure to the main crank-shaft bearings. This lubrication system

also followed the German practice in allowing the overflow in the main bearings to travel out the face of the crank cheeks to a scupper which collected this excess for crank-pin lubrication. This is very economical in the use of oil and is still the standard German practice.

"The present system is similar to the first practice, except that the oil, while under pressure, is not only fed to main bearings but through holes inside of crank cheeks to crank pins, instead of feeding these crank pins through scuppers. The difference between the two oiling systems consists of carrying oil for the crank pins through a hole inside the crank cheek instead of up the outside face of the crank cheek.

"Propeller hub.—The Hall-Scott propeller-hub design was adapted to the power of the Liberty engine.

"Water pump.—The Packard type of water pump was adapted to the Liberty.

"Carburetor.—A carburetor was developed by the Zenith Co. for the Liberty engine.

"Bore and stroke.—The bore and stroke of the Liberty engine is 5 by 7 inches, the same as the Hall-Scott A-5 and A-7 engines, and as in the Hall-Scott 12-cylinder engine.

"Remarks.—The idea of developing Liberty engines of 4, 6, 8, and 12 cylinders with the above characteristics was first thought of about May 25, 1917. The idea was developed in conference with representatives of the British and French missions, May 28 to June 1, and was submitted in the form of sketches at a joint meeting of the Aircraft (Production) Board and the Joint Army and Navy Technical Board, June 4. The first sample was an eight-cylinder model, delivered to the Bureau of Standards July 3, 1917. The eight-cylinder model, however, was never put into production, as advices from France indicated that demands for increased power would make the eight-cylinder model obsolete before it could be produced.

"WORK ON THE 12-CYLINDER ENGINE.

"Work was then concentrated on the 12-cylinder engine, and one of the experimental engines passed the 50-hour test August 25, 1917.

"After the preliminary drawings were made, engineers from the leading engine builders were brought to the Bureau of Standards, where they inspected the new designs and

made suggestions, most of which were incorporated in the final design. At the same time expert production men were making suggestions that would facilitate production.

"The Liberty 12-cylinder engine passed the 50-hour test, showing as the official report of August 25, 1917, records 'that the fundamental construction is such that very satisfactory service with a long life and high order of efficiency will be given by this power plant, and that the design has passed from the experimental stage into the field of proven engines'.

"An engine committee was organized informally, consisting of the engineers and production managers of the Packard, Ford, Cadillac, Lincoln, Marmon, and Trego companies. This committee met at frequent intervals, and it is to this group of men that the final development of the Liberty engine is largely due."

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